

AN ABSTRACT OF THE THESIS OF

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Title CRITICAL THINKING ABILITIES AND UNDERSTANDING OF  
SCIENCE BY SCIENCE TEACHER-CANDIDATES AT OREGON STATE  
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This investigation was designed to determine the extent to which students who are completing planned curricula in science education are proficient in aspects of critical thinking, and possess understandings of science consistent with those of the practicing scientist. The effects of science curricula upon the development of these abilities and understandings were examined by comparing group mean test scores of science teacher-candidates to those of (a) freshmen in social science education, (b) science education freshmen, (c) elementary teacher-candidates, (d) social science teacher-candidates, and (e) in-service science teachers represented by Academic Year Institute Participants. Subgroups of science teacher-candidates were compared in order to assess further the effect of science curricula upon the development of critical thinking ability and understanding of science.

Criterion tests were the Cornell Critical Thinking Test, Form X, and the Test on Understanding Science, Form W. The study being of a post-test only design, the criterion instruments were administered to the freshmen and in-service teachers at the beginning of Fall Term 1964. Teacher-candidates completed these tests during the term that they were enrolled in their respective special teaching methods courses.

Single classification analyses of covariance using CCTT and TOUS group means were employed to statistically test the null hypotheses. Combined verbal and mathematical subtest means on the Scholastic Aptitude Test were applied as covariance controls of scholastic aptitude while group mean accumulative grade point averages were similarly used to control for group differences in academic achievement. F ratios were computed and evaluated to determine whether differences in group means on the criterion instruments were significant. The data were further analyzed to determine correlations among the variables and to assess prevalent misunderstandings of science.

## FINDINGS

The following conclusions were drawn from the data analyzed in this investigation:

1. Both critical thinking abilities and understanding of science

by the science teacher-candidates were significantly (five percent level) greater than were those of freshmen in social science education, freshmen in science education, elementary teacher-candidates, and in-service science teachers.

2. Science teacher-candidates did not differ significantly from social science teacher-candidates in either critical thinking ability or in understanding of science.
3. Neither critical thinking ability nor understanding of science, as measured by the criterion tests, were major learning outcomes of the study of college science. This conclusion was based on:
  - a) Negative or non-significant correlations between both CCTT and TOUS scores and the total number of science grade points earned by members of each group.
  - b) Lack of a significant difference in critical thinking ability or in understanding of science between science teacher-candidates and social science teacher-candidates, the latter group having completed half as many credits in science as had the former.
  - c) Failure to find a significant difference in either critical thinking ability or understanding of science between high and low subgroups of science teacher-candidates

selected on each of the following bases:

- 1) Total number of science grade points earned.
  - 2) The biological-physical science ratio of science credits completed.
4. Science teacher-candidates evidenced an understanding of science superior to that of groups of students similar to those which they would be expected to teach.
  5. Science teacher-candidates and in-service science teachers evidenced several misconceptions of the nature of science and scientists as did the non-science oriented groups.
  6. Although all the groups revealed misunderstandings of the nature of scientific models, hypotheses, theories, and laws, these misunderstandings were significantly more numerous for the groups whose members had studied relatively little college science.

CRITICAL THINKING ABILITIES AND UNDERSTANDING  
OF SCIENCE BY SCIENCE TEACHER-CANDIDATES  
AT OREGON STATE UNIVERSITY

by

GENE FRANCIS CRAVEN

A THESIS

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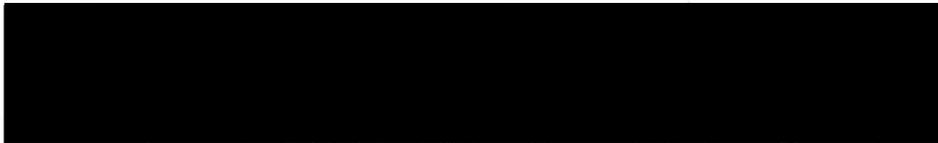
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CRITICAL THINKING ABILITIES AND UNDERSTANDING  
OF SCIENCE BY SCIENCE TEACHER-CANDIDATES  
AT OREGON STATE UNIVERSITY

CHAPTER I

INTRODUCTION

The 1960's have been characterized by the introduction of new science curricula into the secondary school. These new programs present science as a scientist sees science and in terms of modern concepts and theories.

Curriculum reform in science has resulted largely from social change and from the impact of science on our culture. Most of our citizens are aware that the applications of science are essential to human welfare, modern economy, daily conveniences, and national survival. Yet, there is danger that understandings of science as processes whereby man has first-hand experiences with natural phenomena, may not be clear. Science needs wide public understanding and support, for it is largely through this means that the work of the scientists is sustained.

The importance of understanding science is emphasized by the Commission on Science of the American Association for the Advancement of Science which stated that (64, p. 6)

The goals of the new science courses center upon the development of an understanding of the nature of science, its modes of inquiry, and its conceptual

innovations; and the understanding of natural phenomena and the place of science in the activity of man. The achievement of these goals will result in a student who is literate in science and one who is capable of a citizen's participation in a science oriented society.

The importance of ability to think critically was stressed by the Educational Policies Commission of the National Education Association in its statement (30, p. 4)

To be free, a man must be capable of basing his choices on understandings which he himself achieves and on values which he examines for himself. He must be aware of the bases on which he accepts propositions as true. He must understand the values by which he lives, the assumptions on which they rest, and the consequences to which they lead. He must be capable of analyzing the situation in which he finds himself and of developing solutions to the problems before him. . . . he has a rational grasp of himself, his surroundings, and the relation between them.

The science teacher at the elementary, secondary, or collegiate level is in a unique position to further the rational abilities and the understandings in science of the students he teaches.

During the decade, 1955 - 1965, science teaching has been more critically examined than in any comparable period. Commissions such as those cited above have been joined by interested and influential individuals and organizations to formulate objectives, and to prepare curricular materials that better educate citizens to contribute effectively in a rapidly changing science based society. Their conclusions are reflected in the curriculum materials developed by groups such as the Physical Science Study Committee, the Chemical

Education Materials Study, and the Biological Sciences Curriculum Study.

The National Science Foundation, recognizing that the classroom teacher is a key figure in any formal learning situation, has generously supported programs developed by colleges and universities to prepare in-service teachers to more adequately teach science. The National Science Teachers Association, the American Association for the Advancement of Science, and state certification agencies have joined institutions preparing teachers in re-examining requirements for both pre- and in-service education of teachers. This has resulted in modifications of curricula for teacher education by several of these institutions.

It is necessary to evaluate periodically the competencies of teacher-candidates in order to assess the strengths and weaknesses of teacher education programs and to determine the extent to which curricular modifications have been successful. The competencies which this study deals with are among those which teachers of the new high school science curricula are expected to develop in their students.

#### Statement of the Problem

The purpose of this study was to compare the understanding of science and the critical thinking abilities of science teacher-

candidates to those of in-service science teachers represented by 1964-65 Academic Year Institute Participants; to freshmen in social science and science education; and to teacher-candidates in social science and elementary education at Oregon State University.

More specifically, answers were sought to the following questions:

1. To what extent are science teacher-candidates proficient in critical thinking as measured by the Cornell Critical Thinking Test?
2. To what extent do science teacher-candidates possess an understanding of science as measured by the Klopfer Test On Understanding Science?
3. To what extent do students who are completing curricula in science education differ in critical thinking abilities from:
  - a. In-service science teachers represented by Academic Year Institute Participants?
  - b. Students completing curricula in social science and elementary education?
  - c. Freshmen matriculating in social science and science education?
4. To what extent do students who are completing curricula in science education differ in understanding of science

from:

- a. In-service science teachers represented by Academic Year Institute Participants?
  - b. Students completing curricula in social science and elementary education?
  - c. Freshmen matriculating in social science and science education?
5. To what extent do selected, planned curricula in college science develop critical thinking abilities and understanding of science of science teacher-candidates?

This study is designed to investigate the above questions based on the assumption that teachers of science should possess an understanding of science and the scientific enterprise consistent with that of the practicing scientist if they are to effectively develop this understanding in their students. It is further assumed that teachers should be proficient in critical thinking if they are to teach for and develop most effectively this ability in their students.

### Definition of Terms

#### Teacher-Candidates

Teacher-candidates are defined as those students at Oregon State University who are in the process of completing a prescribed curriculum in teacher education. In this study, teacher-candidates

consisted of junior and senior students who were registered for special elementary or secondary methods courses. These students had completed a major portion of the course work in their respective curricula.

### Science Teacher-Candidates

Science teacher-candidates are defined as teacher-candidates in the process of completing curricula prescribed by Oregon State University (70, p. 198-199) to fulfill certification requirements to teach general science, biology, chemistry, physics or mathematics and who were students in Special Secondary Methods courses in science or mathematics during the 1964-65 academic year.

### Critical Thinking

Good (43, p. 424) defines critical thinking as thinking that proceeds on the basis of careful evaluation of premises and evidence and comes to conclusions cautiously through the consideration of all pertinent factors. This concept of critical thinking was more precisely defined by the author of the critical thinking test used in this study as "the ability to correctly assess statements" (36, p. 599). Statements on this test were designed to measure proficiency in:

1. Induction: ability to judge whether a simple generalization or hypothesis is warranted.

2. Reliability: ability to judge whether an observation statement is reliable.
3. Deduction: ability to judge whether a statement follows from the premises.
4. Assumption-finding: ability to judge whether something is an assumption.

Critical thinking, as used in this study, refers to student proficiency in these four abilities.

### Understanding of Science

By understanding of science is meant how the student perceives, understands, or has knowledge about the nature of science, its place in our society, and how scientists behave and operate, both as an occupational group and as citizens. The evaluation instrument used in this study was designed to measure understandings about (21, p. 3-6):

1. Science as an institution: the human element in science, communication among scientists, scientific societies, interaction of science and society.
2. Scientists as people: generalizations about scientists as people, institutional pressures on scientists, abilities needed by scientists.
3. Aims of science and the processes of science: tactics and

strategy of sciencing, generalities about scientific methods, aims of science, science and technology, unity and interdependence of the sciences.

It is these understandings which define the term "understanding of science" for the purposes of this study.

### Scholastic Aptitude

Scholastic aptitude is ability to engage profitably in academic work. Scores on the College Entrance Examination Board Scholastic Aptitude Test are commonly used as measures of scholastic aptitude at the college and university level. For the purposes of this study, scholastic aptitude is defined as that which is measured by scores on the verbal and mathematical subtests of the Scholastic Aptitude Test (23), to be designated as SAT (V + M).

### Academic Achievement

Academic achievement refers to the quality of the student's academic work as measured by his accumulative grade point average based on all college coursework completed prior to the term during which the criterion tests were administered. Grade point averages reported in this study were based on a four-point scale whereby a student who received an "A" grade in a three credit course earned 12 grade points, if he earned a "B" he received nine grade points,

and so forth. Accumulative grade point averages are computed by dividing the total number of grade points earned by the total number of credits completed.

### Criterion Tests

Criterion tests are defined as those evaluation instruments which were used to test the hypotheses investigated in a study. The criterion tests used in this study were the Cornell Critical Thinking Test, Form X and the Test on Understanding Science, Form W.

### Basic Assumptions

In this study it was assumed that:

1. Student learning is related to the curriculum studied.
2. The critical thinking abilities and the understanding of science by science teachers directly and significantly influence the quality of secondary science teaching.
3. Critical thinking abilities and understanding of science can be analyzed into a number of components for the purpose of evaluation.
4. The Cornell Critical Thinking Test validly and reliably measures aspects of critical thinking.
5. The Test On Understanding Science validly and reliably measures understanding of selected aspects of science.

6. The Scholastic Aptitude Test scores provide a valid and reliable measure of the student's general academic ability.
7. The student's accumulative college grade point average provides a valid and reliable measure of his academic achievement.

#### Hypotheses To Be Tested

The investigator's educational hypothesis was based on the assumption that student learning is related to the curriculum studied. This assumption is implicit in all curriculum development, including that for teacher education. Assuming that this is true, the investigator hypothesized that students who are nearing the completion of programs specifically designed for the education of science teachers differ in critical thinking abilities and in understanding of science from students who: (a) have not yet begun curricula specifically designed for the education of teachers, (b) are completing curricula designed to educate non-science teachers, or (c) are experienced science teachers.

In order to test these educational hypotheses, the following null hypotheses were proposed:

1. There is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability

- of freshmen matriculating in social science education.
2. There is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability of freshmen matriculating in science education.
  3. There is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability of teacher-candidates in social science.
  4. There is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability of teacher-candidates in elementary education.
  5. There is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability of in-service science teachers represented by National Science Foundation sponsored Academic Year Institute Participants.
  6. There is no difference in understanding of science between science teacher-candidates and understanding of science of freshmen matriculating in social science education.
  7. There is no difference in understanding of science between science teacher-candidates and understanding of science of freshmen matriculating in science education.
  8. There is no difference in understanding of science between science teacher-candidates and understanding of science of

teacher-candidates in social science.

9. There is no difference in understanding of science between science teacher-candidates and understanding of science of teacher-candidates in elementary education.
10. There is no difference in understanding of science between science teacher-candidates and understanding of science of in-service teachers represented by Academic Year Institute Participants.
11. There is no difference in critical thinking ability between science teacher-candidates in high and low subgroups based on the total number of science grade points earned.
12. There is no difference in critical thinking ability between science teacher-candidates in high and low subgroups based on the biological science-physical science ratio of science credits completed.
13. There is no difference in critical thinking ability between science teacher-candidates in high and low subgroups based on the number of mathematics credits completed.
14. There is no difference in understanding of science between science teacher-candidates in high and low subgroups based on the total number of science grade points earned.
15. There is no difference in understanding of science between science teacher-candidates in high and low subgroups based

on the biological science-physical science ratio of science credits completed.

16. There is no difference in understanding of science between science teacher-candidates in high and low subgroups based on the number of mathematics credits completed.
17. There is no difference in critical thinking ability between male and female science teacher-candidates.
18. There is no difference in understanding of science between male and female science teacher-candidates.

#### Delimitation of the Study

The study has been delimited as follows:

1. The population consisted of students at Oregon State University during the 1964-65 academic year. It included:
  - a. All freshmen matriculating in social science and science education who completed at least two terms work at Oregon State University.
  - b. All elementary teacher-candidates who were enrolled in science and mathematics methods courses during Fall Term 1964 for whom Scholastic Aptitude Test scores were available.
  - c. All social science and science teacher-candidates enrolled in Special Secondary Methods courses for

whom Scholastic Aptitude Test scores were available.

- d. All of the in-service science teachers represented by Academic Year Institute Participants who were (1) American citizens and (2) who completed the linguistic and mathematical sections of the Scholastic Aptitude Test.
2. Critical thinking ability and understanding of science were the only factors of concern in this study.
3. The instrument used to measure critical thinking abilities was a 50 minute test limited to the following aspects of critical thinking:
  - a. Induction: evaluation of evidence for or against a hypothesis.
  - b. Reliability: evaluation of the reliability of information.
  - c. Deduction: logical reasoning ability.
  - d. Assumption-finding: recognition of assumptions.
4. The instrument used to measure understanding of science was a 40 minute test limited to the following areas:
  - a. Understandings about the scientific enterprise.
  - b. Understandings about scientists.
  - c. Understandings about the methods and aims of science.
5. Evidence used to describe the students and to assist in some of the interpretations came from college transcripts

from the Office of the Registrar at Oregon State University or the college transcripts on file in the Office of the Director of the Academic Year Institute at Oregon State University.

### Importance of the Study

The importance of this study rests on the assumption that critical thinking abilities and the understanding of science by science teachers directly and significantly influence the quality of their science teaching.

The freshmen, teacher-candidates, and in-service science teachers who participated in this study have never been scientists. Their understandings of science and scientists have come from their formal and informal educational experience with science and the scientific enterprise. If these student's understandings of the characteristics of scientists and the nature of science are consistent with those of the scientist, this fact should be known. If, on the other hand, it could be shown that science teachers and science teacher-candidates express understandings of science which indicate misunderstandings, even misconceptions, about the nature of science, then we face a major problem in the education of science teachers. There is a possibility of correcting the misconceptions if we can identify them.

If it could be shown that the number and types of science courses studied by teacher-candidates are significantly related to their understandings of science, then curricula could be designed, the study of which would result in more realistic understandings of science.

Teachers of almost all courses, whether they be in science, social science, or some other discipline, would like for their students to be able to apply the knowledge and techniques of their discipline to significant issues and problems. If the study of a particular teacher education curriculum results in greater gains in critical thinking ability (an aspect of general problem solving ability) than does the study of some other sequence of courses, this fact should be known. If, on the other hand, gain in critical thinking is small or non-existent, then we are confronted with the problem of designing a series of learning activities which will be effective in teaching for this widely accepted objective of education. If it is found that there are no significant differences among teacher-education curricula with respect to the development of critical thinking ability, this would have implications for the design of programs for the education of science teachers.

## CHAPTER II

### REVIEW OF RELATED LITERATURE

A review of the literature on science education revealed that many former studies had treated one or more aspects of the problem under consideration in this investigation. No one study was similar in problem or scope to the present one. In this chapter, a series of studies which relate to three aspects of the investigation under consideration will be reviewed. These are:

1. Commonly accepted objectives of general education and science education.
2. Studies concerned with the development of critical thinking ability.
3. Studies concerned with understandings of the nature of science and scientists.

Over the past half-century, interested and influential individuals and committees have repeatedly examined the objectives of general education. The period since the launching of the Russian Sputnik in October 1957 has been particularly productive in this respect. Many statements of objectives have been formulated. Curricula have been designed and teaching procedures have been developed to achieve these objectives. Numerous studies have been conducted to assess

the extent to which various curricular materials and teaching procedures contribute to student attainment of specified learning outcomes.

There is agreement, both in principle and practice, that curriculum development consists of four phases:

1. Selecting learning outcomes which are most worth learning.
2. Choosing the subject matter which is best adapted to the realization of those learning outcomes.
3. Selecting the most economical teaching methods that will affect the realization of the desired learning outcomes.
4. Developing an evaluation program that will reveal the extent to which the desired learning outcomes have been attained.

It is clear that the objectives (learning outcomes) of education play a vital role in any consideration of the teaching-learning process.

#### Objectives of General Education

One of the most extensive evaluations of educational objectives at the college level was that undertaken by the Cooperative Study of Evaluation in General Education, sponsored by the American Council on Education (29). This three and one-half year study by approximately 50 individuals representing 19 colleges and universities was initiated in 1950 under a grant from the Carnegie Foundation for the Advancement of Teaching. Six intercollegiate committees were set

up to work on objectives which had been identified and accepted by the participating colleges and universities as being important for general education. Each of the committees undertook to:

1. Clarify and possibly redefine the objectives of general education.
2. Develop more adequate and reliable evaluation techniques.
3. Collect evidence on student achievement.

All of the colleges and universities participating in this study accepted the objective, "To understand the common phenomena in one's physical environment, to apply habits of scientific thought to both personal and civic problems, and to appreciate the implications of scientific discoveries for human welfare," as suggestive of their hopes with regard to a general education science course. This general objective was more precisely defined by the science committee as consisting of developing the student's (29, p. 103):

1. Ability to apply science knowledge to new problems and situations.
2. Ability to analyze scientific data summarized in maps, tables, curves, charts, and graphs.
3. Ability to read and evaluate news articles and popular writing on scientific developments.
4. Understanding of the role - importance and limitations - of science in the modern world.
5. Willingness to face facts, revise judgments, and to change behavior in the light of appropriate evidence.

6. Understanding of the point of view with which a scientist approaches his problems and of the kind of things that he does.
7. Recognition of the need for additional science knowledge in a situation, and the ability to acquire it.

The abilities and understandings specified in this list of objectives consist of (a) understandings of the nature of science, and (b) aspects of critical thinking. The Cooperative Study Committees on critical thinking, humanities, and social science decided independently to also work on objectives involving the concept of critical thinking. Dressel and Mayhew (29, p. 40) stated that the marked similarities of the final lists of objectives formulated by each committee constituted the first source of validity of critical thinking as a major objective of general education. The work of the critical thinking committee resulted in the development of the American Council on Education Test of Critical Thinking, Form G., which the committee employed in a series of studies. This test has been used in several subsequent studies, some of which will be reviewed in the section of this chapter which deals with studies on critical thinking.

A second major endeavor to identify objectives of collegiate education has resulted in the development of two Taxonomies of Educational Objectives by a Committee of Collegiate and University Examiners (17, 18). The primary purpose of this group was to identify and precisely define educational objectives, state them in behavioral

form, and develop a logical classification system for use in evaluating students' attainment of the objectives. Although every attempt was made to avoid value judgments about the objectives and behaviors, the taxonomies do identify important attainable outcomes of college education.

The taxonomy was subdivided into three parts, two of which are now completed. These are (17, p. 7; 18, p. 6):

1. The cognitive domain, which includes those objectives which deal with recall or recognition of knowledge, and the development of intellectual abilities and skills.
2. The affective domain which includes changes in interest, attitudes, and values, and the development of appreciations.

The objectives included in each of the domains were rather precisely identified and defined by the committees. Included among the intellectual abilities and skills in the cognitive domain are (a) skill in predicting continuation of trends, (b) the ability to recognize unstated assumptions, (c) skill in distinguishing facts from hypotheses, (d) ability to propose ways of testing hypotheses, and (e) the ability to indicate logical fallacies in arguments.

Both the committees responsible for the development of the Taxonomies, and the committees of the Cooperative Study recognized the importance of the development of intellectual abilities, including critical thinking, as important outcomes of a college education. Although these groups were not specifically concerned with the education

of science teachers, their recognition of the importance of critical thinking and, in the case of the Cooperative Committee on Science, the development of realistic understandings of science, is consistent with statements of objectives of science education which have been made by interested and influential individuals and groups concerned with pre-college education in science.

### Objectives of Science Education

The long range objectives presented by the National Science Teachers Association in 1961 (84, p. 28) included the following statements:

1. As a result of science education, students should habitually and skillfully employ sound thinking habits in meeting problem situations... To do this, young people must have an understanding of, faith in, and direct practice with sound methods and attitudes of thought.
2. Students must acquire a working concept of the relations between science and society, science and individuals, and science and technology.
3. Students... should know something of the development of science and of the people who have contributed toward it.
4. They should not only carry on sound thinking, they should have a fund of reliable knowledge with which to think...

In Rethinking Science Education, Hurd (52, p. 33) stated that the objectives of science teaching, as they appear in educational literature, have changed little in the past 25 years. He included the following in a listing which he suggested might provide a model for

curriculum development (52, p. 33-37):

1. Understanding of science. Pupils should acquire a useful command of science concepts and principles... they should learn something about the character of scientific knowledge, how it has been developed, and how it is used.
2. Problem-solving. Science is a process..focused upon inquiry and subsequent action. A process of inquiry involves careful observing, seeking the most reliable data, and then using rational processes to give order to the data and to suggest possible conclusions or further research.
3. The social aspects of science. A student should understand the relation of basic research to applied research, and the interplay of technological innovations and human affairs.
4. Abilities. Young people need to acquire those skills and abilities which will enable them to assume responsibility for expanding their own learning. Some of these are:
  - a. Locating authoritative sources of science information.
  - b. Making valid inferences and predictions from data.
  - c. Recognizing and evaluating assumptions.
  - d. Recognizing pertinency and adequacy of data.

Objectives for modern science teaching formulated by the Commission of Science Education of the American Association for the Advancement of Science were summarized by Kessen (59, p. 4-6) as:

1. Science as inquiry. Science is best taught as a procedure of inquiry. ... it is a structured and directed way of asking and answering questions. The procedures of scientific inquiry... can be applied without limit.
2. The scientific attitude. The discipline of scientific inquiry demands respect for the work of the past

together with a willingness to question the claims of authority. The attitude of intelligent caution, the restraint of commitment, the belief that difficult problems are always susceptible to scientific analysis, the courage to maintain doubt... will be learned through inquiry.

3. The procedures of science. The statement of a problem...ability to recognize and use sources of reliable information...ability to observe...comparison of phenomena...and ability to evaluate evidence and draw conclusions...should be developed.
4. Scientific knowledge. A knowledge of the basic findings about the universe...the structure and reactions of matter...the conservation and transformation of energy ...the interaction of living things and their environment ...give boundaries and direction to scientific inquiry.

Cohen (16, p. 32-33), in an address delivered at the National Science Teachers Association Convention in Chicago in March 1964, included the following as important values and goals for science teaching:

1. To provide enough understanding to enable the educated citizens to collaborate intelligently with those who are actively engaged in scientific pursuits.
2. To enable the citizen both to criticize and to appreciate the effects of the sciences on his society.
3. To give a practical grasp of scientific methods of grappling with problems, at least sufficient for problems which the student will face in his individual and social life.
4. To understand the place of science among other intellectual and esthetic pursuits: briefly, to see the sciences as being themselves a humanistic enterprise.
5. To provide our students with rich and various experiences of individual thinking and critical attitudes.

In a report by the Joint Commission on the Education of Teachers of Science and Mathematics of the American Association for the Advancement of Science and the American Association of Colleges for Teacher Education (57, p. 11), it is stated that the primary goals of the study of biological and physical science

... should be to provide genuine understanding, to stimulate reflection, and to promote self-teaching --in short, to develop a curiosity for, and literacy in the natural sciences which will motivate the student to continue to satisfy his interest by independent study after he has left school.

The United States President's Science Advisory Committee, in its statement Education for the Age of Science (89, p. 1, 30), presented the view that:

A modern educational system should not only sharpen the intellectual capacities and curiosities of each generation, should not only extract the essential core from ever-accumulating stores of knowledge...; it must also produce citizens and leaders who will know how to use the knowledge and tools to advance social and cultural life.

...we should improve our scientific education at all levels, attempting to give better understanding of science to the non-scientist as well as to discover and stimulate more individuals who have talents to become scientists and engineers.

### Summary

A review of the literature on the objectives of science education reveals that while there is not complete agreement on the specific

objectives, three fairly clear-cut objectives emerge. These may be summarized as:

1. To become knowledgeable with the significant scientific facts upon which the major concepts and theories of science rest.
2. To develop abilities and a predisposition to critically judge the merit of things, to satisfactorily solve significant problems, and to successfully pursue a life-long interest in learning.
3. To acquire a realistic understanding of the nature of science, the influence of society upon the direction and application of scientific endeavors, and the interplay of technological innovations and human affairs.

#### Development of Critical Thinking Ability

Burton, Kimball, and Wing (13, p. v) asserted that "Teaching students to think", is one of the most commonly expressed aims of education, generally, and in almost any subject field. Anderson (3), Dale (24), Dressel (28), and Fox (39) are but a few who could be cited that concur with this point of view.

Burton, Kimball, and Wing (13, p. 242) pointed to studies by Furst (40), Apler (2), and Techman (85) as examples of those which consistently showed moderate positive relationships between general

intelligence and various thinking skills. This suggested to these investigators the possibility that students may possess some general critical thinking ability, just as they possess general intellectual ability.

Dressel and Mayhew (29, p. 56) reported that scores on the American Council on Education Test of Critical Thinking were positively correlated to grades in general education courses in social science at about the same magnitude as are the tests of knowledge or intelligence. They also found that scores on this test continued to increase or remain constant during the second year. These investigators cited learning psychologists who have established that forgetting of knowledge begins almost immediately after a learning experience.

A wide variety of studies by Bloom and Broder, Burack and Moos, and others were cited by Burton, Kimball, and Wing (15, p. 243) as having established clearly that knowledge of the principles in a particular field of knowledge in no way assures that these principles will be properly applied in problem-solving situations. Ennis (35) contended that some people who are good critical thinkers in one subject matter area are not so in another area.

Edwards (31) identified investigations by Glaser in the field of language arts, Thelen in chemistry, and Fawcett in geometry as outstanding studies in critical thinking. Each of these men concluded

that it is possible to teach the various subjects in such a way that the pupils are led to think critically about problems which concern them. Several studies which support this conclusion will now be briefly reviewed.

In a comprehensive study of high school biology teaching in Oregon, Howe (50, p. 202) reported that 44 of 51 biology classes obtained positive gains between September and May, as measured by the Watson-Glaser Critical Thinking Appraisal. Most of the high gains were associated with classes utilizing problem solving techniques with direct instruction and practice in critical thinking. This finding is consistent with numerous studies which Watson (92, p. 1040) cites as showing that when a particular goal is explicitly taught for, the pupils receiving this instruction achieve higher scores than do untutored controls.

Henderson (47), Rust (77), and Wallen (91) conducted three rather extensive experiments to determine the effect of curricula studied upon the development of critical thinking abilities. In each of these studies, two or more critical thinking tests were employed. All three investigators reported either low inter-correlations or significant differences between the two or three tests used in their respective studies.

Henderson (47) reported an experiment on the teaching of logical and critical thinking which involved 36 teachers and

approximately 1500 students in classes in English, geometry, science, and social studies in grades 9 through 12. Special problem-solving activities were provided which required students to employ aspects of critical thinking in their solutions. The mean gain from September to June on the Watson-Glaser Critical Thinking Appraisal was significant in favor of the experimental classes. Mean gains on the ACE Test of Critical Thinking were not significant at the five percent level, however.

Rust (77) reported a large scale attempt to teach critical thinking which involved approximately three thousand students. Approximately one-third of these served as a control group. The remainder were given instruction and practice in the processes of critical thinking in connection with the subjects of English, social studies, science and mathematics. Only a small number of differences between experimental and control groups were statistically significant. A low inter-correlation was found among the Watson-Glaser Test, the American Council on Education Test, and a test of critical thinking prepared by the investigator.

Wallen (91) conducted a study involving seven teachers of U. S. history who introduced curriculum modifications consisting of a three week unit in critical thinking followed throughout the year by application to course content. This experimental group showed greater gain on an Induction, Deduction, Semantics Critical Thinking

Test constructed by Ennis (33), than did students in similar classes taught by these same teachers the preceding year. There was essentially no difference in gain between the experimental and control groups on the Watson-Glaser Test, however.

The three rather extensive studies cited above show that specially prepared materials and teaching procedures may be used to develop critical thinking abilities. The different tests of critical thinking which were used in these studies appear to have measured different aspects of critical thinking. Various curricular modifications seem to have resulted in the development of different critical thinking abilities.

Many other studies revealed that gains in critical thinking occur when special efforts are made to teach for this objective. For example, Herber (49), in a study involving pairs of tenth, eleventh, and twelfth grade students matched according to sex, grade and course, investigated the effect of materials designed to teach aspects of critical thinking. He found that the use of these materials twice a week for 12 weeks by the experimental group resulted in improvement in critical thinking ability. It was also reported that the variables, sex, grade, and course do affect development of critical thinking ability. Transfer of training in critical thinking was not evident, however. Chenoweth (15) and Rothstein (75) conducted studies in the social studies which support the conclusion that students

who studied materials designed to develop reflective thinking showed significant gains in these abilities.

Rickert (74) found that students who had studied a one semester experimental physical science course in which they were provided with opportunities to analyze problems, to examine assumptions, to collect and organize data, and to test hypotheses, made greater gains on the American Council on Education Test of Critical Thinking than did a physical science survey group, and a physics group. Kastrinos (58) established that biology classes, at each of two levels, which were taught by a principles-critical thinking method, produced greater improvements in critical thinking scores than did classes taught by the same instructors using a textbook-recitation method. Boeck (11), Montague (68), and Edwards (31) conducted separate studies in which experimental chemistry classes which were subjected to learning activities designed to develop critical thinking abilities, showed gains over control classes.

The above studies, along with many others which could be cited, give ample evidence that critical thinking abilities can be developed through the use of appropriately designed learning activities.

Studies by Fogg (38) and Graham (45) demonstrated that teaching methods are important in developing critical thinking ability. Fogg (38) evaluated the effect of two testing techniques on the development of critical thinking by a basic studies freshmen class of 551 students.

One technique utilized the standard five-choice multiple choice item, the experimental format required the testee to indicate all alternatives he was certain were wrong. The growth of the experimental group was significantly greater than that of the control group as measured on the Watson-Glaser Critical Thinking Appraisal.

Graham (45) determined the effectiveness of student-centered and teacher-centered groups in producing significant changes in critical thinking abilities. Eighty students were matched using scores from the Otis Mental Ability Test and the Watson-Glaser Test as pretests. The experimental group gained more in critical thinking than did the control group taught by the same teacher.

Several longitudinal studies reveal that relatively complex abilities such as those of critical thinking are slowly developed. Kopans (61) investigated the relationship between social science as opposed to natural science college specialization with respect to critical thinking ability. Forty neutral and controversial items from the Watson-Glaser Test were selected by a panel of judges. When the subjects were equated for age, intelligence, and social position, significant differences in critical thinking ability, in favor of social science majors, appeared only on controversial issues.

Lehmann (62) reported a study on changes in critical thinking of 1,051 students at Michigan State University from the beginning of freshman orientation week until near the end of their senior year.

Both males and females received significantly higher scores on the ACE Test of Critical Thinking at the end of four years of college. The greatest change occurred during the freshman and sophomore years. There was no evidence that one sex or the other changed more in critical thinking during their four years.

In a study of college teaching in 19 universities and colleges, Dressel and Mayhew (29, p. 391) found that the largest gains in critical thinking were consistently made in the freshman year. It was also noted that institutions having a special course dealing with critical thinking had no advantage over other institutions. The largest gains were made by institutions that had well organized education experiences for the freshman year.

Dressel and Mayhew also found that only small gains are attained in critical thinking when merely a single course in a college program aims to develop this type of competence. On the other hand, when the entire curriculum is devoted to this same purpose, the student gains in critical thinking become very large. These researchers reported that (29, p. 391) "in effect, the entire educational environment must be turned toward the achievement of complex objectives if they are to be attained in any significant way." They concluded that the oft-stated goal of critical thinking was often inadequately achieved because it was seen chiefly as a residue from reading about, or studying, the thinking of others. This is consistent

with the point of view of the National Council for the Social Studies (3, p. vii):

There is little reason to believe that substantial skill in critical thinking may be achieved as an incidental outcome of instruction directed to other means.

In summary, a review of the literature provided considerable evidence that critical thinking abilities can be developed when learning activities are specifically designed for this purpose. Gains in critical thinking ability appeared to be greatest when the entire educational environment is directed toward this goal. There was little evidence, however, that substantial gain in critical thinking ability results from instruction directed toward other learning outcomes.

#### Development of Understanding of Science

Development of realistic understandings of the characteristics of scientists and the nature of science has been included in virtually every major statement of objectives of science education. In addition to the previously cited statements of objectives of science education, Dees (27, p. 7), in addressing the National Association for Research in Science Teaching, emphasized that:

All citizens must somehow achieve better understanding of what science is and what scientists do. To assure such understanding on the part of citizens of the future

is a major job which science education must attempt to accomplish.

The following statement has been formulated by the Committee on Innovation in Laboratory Instruction of the Biological Sciences Curriculum Study (53, p. 144) to be read by high school students:

There are two major aims in studying any natural science. One aim, the lesser in importance, is to become acquainted with the significant facts upon which rest the major concepts and theories of science.

The other aim is indispensable to young scientists and non-scientists alike--to everyone who hopes to participate intelligently in the life of a scientific age which so constantly demands difficult decisions and real wisdom. This second objective is to know what science really is--to recognize its spirit and to appreciate its methods. It is a ... composite of ways of finding out reliable, confirmed knowledge about all natural phenomena. It is compounded of the observations of the human senses and the inferences and deductions that can be derived from such experiences.

A striking similarity in the aims and objectives of nearly all of the recently developed projects in mathematics, physics, biology, chemistry, social sciences, English, and foreign language is noted by Goodlad (44, p. 54) who writes:

Objectives, as they are defined in various descriptive documents, stress the importance of understanding the structure of the discipline, the purposes and methods of the field, and the part that creative men and women played in the development of the field.

Dr. James B. Conant (19, p. 4), in discussing the necessity for an understanding of science by all citizens, said:

... the remedy does not lie in a greater dissemination of scientific information among non-scientists. Being

well informed about science is not the same as understanding science though the two propositions are not antithetical. What is needed is methods for imparting some knowledge of the tactics and strategy of science to those who are not scientists.

These citations appear sufficient to support the importance of developing realistic understandings of science and scientists as a major objective of science education. Unfortunately, few major efforts have been made to teach specifically for this objective. Recently, however, Klopfer and Cooley (60) conducted a rather extensive, rigorously designed study which demonstrated that these understandings can be significantly increased with little or no loss in attainment of the usual subject matter.

These researchers investigated the gain in the understanding of science and of scientists by a sample of more than 2500 students who worked for four weeks with case-study materials drawn from the history of science. In addition, the researchers investigated whether students who had used case studies for four weeks during the school year showed as much achievement in the usual course content (biology, chemistry, and physics) in which they enrolled, as students who had not used the case materials. Measures were also taken on the teacher's understanding of science and scientists. The special criterion instrument designed for the analysis was Form X of the Test on Understanding Science.

Analyses of the data showed that there were highly significant

differences between all of the experimental and control groups in understanding both science and scientists. For the chemistry and physics classes, there was no statistically significant differences between experimental and control groups in achievement in the usual content of these courses. Students in the biology control groups, however, showed more gain in the achievement of the usual content of biology.

The teacher's initial understanding of science was found not to be a significant source of variation in student gain on TOUS. Neither was the type of science course (biology, chemistry, or physics).

This study illustrated that the so-called "intangible" objectives of science instruction can be measured and that, with the expenditure of relatively little class time and through the use of instructional material specifically designed for this purpose, significant student gains in important understandings of science can be achieved.

An investigation of the understandings of science of 55 high school juniors who studied advanced topics in science and mathematics for two weeks, and then worked for eight weeks alongside research scientists in university and industrial laboratories, was reported by Cooley and Bassett (20). The statistically significant changes which were observed involved the student's image of science and scientists, and student plans for college and career. The trends in their image of science and scientists were, in general,

toward increased realism. The distinction between science and technology tended to shift in the direction of increased understanding of the nature of scientific research.

A small study was conducted by Cooley and Klopfer (22) in the summer of 1960 in which the Test on Understanding Science, Form X, was administered as a pre- and post-test to 78 talented high school students in two summer programs. In both of these programs, the students were in active contact with working scientists. The observed significant changes in their responses to items on the Test on Understanding Science was toward the desired "correct" responses at the end of the summer. A similar group of students who were not participating in such summer science programs did not tend to move toward the correct responses.

Smith (80) investigated the extent to which a group of 36 boys and 24 girls attending a summer science training program understood the character of science and scientists. Using the Test on Understanding Science, it was found that both the boys and girls were below average in perception of science and scientists. The boys demonstrated significantly higher understanding of science and scientists than did the girls. TOUS scores and WGCTA scores reflected each other with correlations of .52 and .62 for two groups of boys. For the girls, this relation was non-significant. Smith concluded that the attitudes and mood of science are apparently not

getting through by teaching students indirectly.

A nation-wide survey to determine the image of the scientist among high school students was reported by Mead (67). A representative sample of 35,000 high school students were asked to complete statements relative to science and scientists. In general, the study showed that the students had built up a very positive image of science and the scientist when they were asked to speak without personal career involvements. However, when the question became one of personal contact with science, as a career choice or involving the choice of a husband, the image was overwhelmingly negative. The school was identified by the investigator as having an important role in changing this attitude. Her conclusion was that since most high school students' attitudes closely reflect those of their parents, the findings of the study indicated the climate of opinion in which parents may be expected to back up their children in choosing science as a career, and in voting funds to support scientific endeavors.

Stoker (83) used the Purdue Physical Science Test to measure aptitude and the Purdue Opinion Panel to measure attitude of a nationally representative sample of 2,500 pupils in grades 10, 11 and 12. In general, the pupils expressed favorable attitudes toward science as a social institution. Their attitudes toward scientists and their aptitudes in science were significantly related, but attitudes toward science as a vocation and aptitudes in science were not.

Attitude toward science as an institution, to science as a vocation, and to scientists were closely related to the pupil's grades in science.

College students were found by Beardslee and O'Dowd (6) to reveal in interviews beliefs about scientists which were similar to those found among high school students. The scientist, to use the student phrase, "is not well rounded."

These investigators reported that there is data which shows that students on entering college have a more favorable view of the scientist than students who have already spent a semester in college.

Withey (95) reported a study conducted by the Survey Research Center of the University of Michigan in which it was found that probably not more than 12 percent of the adult population really understands what is meant by the scientific approach. For about two-thirds, science is simply thorough and intensive study. A full quarter freely admitted that they did not know what was meant by studying something scientifically. Only about one in ten talked at all about controlled experimentation, scientific method, measurement, systematic variation, theory, or similar notion.

Attitudes of 516 college-bound seniors toward science and scientists were measured by Belt (9). Twenty items on one of the tests used were exactly the same as in the Purdue Opinion Panel Polls. A comparison of these items in the two studies seemed to indicate that, as a group, relatively high ability pupils had more

favorable attitudes toward science and scientists than did a representative cross section of high school pupils. The college-bound pupils of this study, a group that contained a relatively high percent of pupils with sufficient academic ability to pursue the study of science in college, revealed favorable attitudes toward science and scientists.

Wilson (94) attempted to determine the opinions and attitudes related to certain aspects of science and its place in our society which were held by several groups of high school and college students. A set of 26 statements about science were submitted to five groups of students (one of which consisted of junior and senior science majors), who were asked to indicate agreement or disagreement with each one. Despite the fact that the groups differed considerably in background and training in science, there was considerable uniformity in their reactions to the statements.

Fifty-seven percent of them agreed that the real advances in science consist of the production of useful devices such as automobiles and radios. The majority consider the primary purpose of science to be concerned with the improvement of man's physical comfort. As a group, they thought that scientists are more logical in their approach, and more objective in their outlook, toward problems outside their field of work than other professional people. The investigator concluded that responses of these students to this set of

statements indicated a considerable lack of understanding of science and its place in our society.

A questionnaire technique was employed by Renner (72) to obtain data bearing upon understandings that junior high school students have about the work of the scientist, the engineer, and the technician. A panel of experts from the respective fields was consulted and definitions of the scientists, the engineer and the technician were agreed upon. The data for 1,052 junior high school students suggested that junior high school science contributed little to student understanding of the work of a scientist. The investigator concluded that although junior high school students regress in their understandings of a scientist's work, and they do, in general increase their understandings of the work of the engineer, they leave junior high school with a greater understanding of the work of a scientist than the work of an engineer or technician.

Hubbard (51) investigated the junior high school students' perception of science as an institution and scientists as an occupational group, and changes which occurred when selected classes received an introductory unit of instruction concerning the ways of the scientist. Using the Facts About Science Test, he found that perceptions of science and scientists held by eighth graders were fairly accurate concerning some of the aims, limitations, and processes of science, and, to a lesser extent concerning the behavior of scientists as

people. The experimental group which received the introductory unit of instruction concerning the ways of the scientist did not do significantly better on the total test than did the matched control group.

In a comprehensive study of the attitudes of high school seniors toward science and scientific careers, Allen (1) showed that attitudes were favorable and constructive toward science when judged by the responses provided by a jury. On the other hand, an item analysis of all responses revealed the existence of misunderstandings on the part of many students on questions related to the scientist and his work, and to the nature of science. The greater the intelligence of a given senior, the greater the chances were that he would have favorable attitudes toward science.

Using a slightly modified form of the instrument developed by Allen, Howe (50) found that 40 of 51 biology classes evidenced attitude changes in the direction of the attitudes held by scientists. While there was not close agreement between the scientists and the students on several of the statements, the analysis indicated that these classes had generally positive attitudes toward science. Evidence was obtained which showed that the attitudes of the classes changed in the direction of the attitudes of the classroom teacher in a majority of the classes.

The significance of these studies, most of which reveal the lack

of a realistic understanding by science teachers and their students of certain aspects of science, was emphasized in a statement by Richardson et al. (73, p. 262, 266) who asserted:

That all science teachers must be competent in the subject-matter area they teach is accepted by academicians and educators alike, for without this knowledge they simply cannot teach.

...He (the science teacher) should come to understand science, with its unique purposes and procedures, as a function of society...

This point of view is supported by Stollberg (84, p. 62) who, in the NSTA publication Planning For Excellence in High School Science, concluded that:

If the science teacher is to teach with equal facility both the process and product goals of science, he must himself experience these concepts in the science courses comprising his pre-service training.

In summary, the findings of several nationwide surveys and studies indicate high school students' understanding of the scientific enterprise and of science is somewhat inadequate in terms of the present and future role of science in our society. Even more serious than the lack of understanding, are certain misconceptions of science and scientists which are held by both high school students and their science teachers. Research which has been cited, reveals that when the so-called intangibles such as understanding of science are

identified, learning activities can be organized which further student understandings of the nature of science and the characteristics of scientists.

## CHAPTER III

### DESIGN OF THE STUDY

The design of this study was directed principally toward the investigation of two related questions, (a) Do students who study in a curriculum specifically designed for the preparation of science teachers differ in critical thinking abilities and understandings of science from students who study in curricula specifically designed to prepare teachers in other areas? and (b) Do students who complete a curriculum specially designed for the preparation of science teachers differ from high school graduates and high school science teachers in critical thinking ability and understanding of science? These two questions were investigated by a series of analyses of data collected on tests and from college transcripts.

The purpose of the analyses was to determine whether students who were nearing the completion of a curriculum designed specifically for the preparation of science teachers, possessed critical thinking abilities and understandings of science which exceeded those of students who were completing curricula in which less science was studied. The investigator hypothesized that there might be differences in mean scores on the criterion instruments depending upon the curriculum studied. Furthermore, a student's performance on

the criterion instrument was hypothesized to be, in part, a function of his general scholastic aptitude and of his academic achievement in college. Thus, the design used to test the null hypotheses was an analysis of variance with covariance adjustments for scholastic aptitude and academic achievement in college.

The criterion instruments used to test the null hypotheses were the Test on Understanding Science, Form W, published by Educational Testing Service, and the Cornell Critical Thinking Test, Form X, an experimental edition, copies of which were obtained from Dr. Hulda Grobman, Consultant for the Biological Sciences Curriculum Study, with permission of its author, Robert Ennis. Verbal and mathematical subtests of the Scholastic Aptitude Test, published and administered under the direction of the College Entrance Examination Board, were used to measure scholastic aptitude. Accumulative college grade point averages, obtained from college transcripts, were used as measures of the academic achievement of the subjects.

### The Experimental Design

The research design was suggested by Campbell and Stanley (41, p. 195) and Henderson (48, p. 1007-8). Campbell and Stanley contend that:

While the pretest is a concept deeply embedded in the thinking of research workers in education, it is not actually essential to true experimental designs.

... Many problems exist for which pretests are unavailable, inconvenient, or likely to be reactive, and for which (this) design is greatly underused in educational and psychological research.

The research design described by Campbell and Stanley may be designated

$$\begin{array}{ccc} R_1 & X & O_1, O_2 \\ R_2 \dots R_6 & & O_1, O_2 \end{array}$$

Three groups of teacher-candidates, one group of in-service science teachers, and two groups of freshman students ( $R_1, R_2, R_3, R_4, R_5, R_6$ ) were selected. Science teacher-candidates,  $R_1$ , served as the experimental group; the experimental variable,  $X$ , was the curricula which had been specifically designed for the pre-service preparation of science teachers. The other groups which had not been exposed to the experimental variable, were considered to have served as controls. The Cornell Critical Thinking Test and the Test On Understanding Science were the criterion instruments,  $O_1$  and  $O_2$ .

In discussing reasons why it is difficult to give up "knowing for sure" that the experimental and control groups were "equal" before the differential experimental treatment, Campbell and Stanley state (41, p. 195):

The most adequate all-purpose assurance of lack of initial biases between groups is randomization. Within the limits of confidence stated by the tests of significance, randomization can suffice without the pretest.

In this study, differences in academic ability and academic achievement were considered to be factors which would affect criterion test scores and were controlled through covariance techniques. Since the population of each group for which Scholastic Aptitude Test scores were available was small, the entire population was included in the study. This being the case, the present study was considered to fulfill the requirements of the Posttest-Only Control Group Design as described by Campbell and Stanley.

Henderson (48, p. 1007-8) describes a research model which he symbolizes,  $T(x, y, z)$ . This is interpreted as meaning:

Teaching can be conceived as the ternary relation:  $x$  teaches  $y$  to  $z$  where... the domain of ' $x$ ' is the set of persons who act as teachers; the domain of ' $y$ ' is a set of knowledge, beliefs or skills selected (to be taught); and the domain of ' $z$ ' is a set of individuals... who are taught by a teacher.

Although this study was not directly concerned with the teacher, it was concerned with (48, p. 1008):

The relationship between subject matter taught a student and his behaviors subsequent to having been taught it. This kind of research may be thought of as curricular research.

Curricular research is symbolized by Henderson as  $(y, z)$  through a modification of his general research model,  $T(x, y, z)$ . The different curricula studied by teacher-candidates were considered to represent the sets of knowledge, beliefs and skills while criterion test scores represented student behavior from which specified critical

thinking abilities and understandings of science were inferred.

### The Population

The research plan of this study was to investigate the critical thinking abilities and understandings of science of science teacher-candidates. These abilities and understandings were compared to those of: (a) college freshmen matriculating in social science education, (b) freshmen matriculating in science education, (c) elementary teacher-candidates, (d) social science teacher-candidates, and (e) in-service science teachers represented by Academic Year Institute Participants. The purpose of this section is to provide a description of these six groups of students who participated in the study.

#### Freshmen - Social Science Education

Freshmen in social science education included all students matriculating in social science education at the beginning of Fall Term 1964 who completed at least two terms work at Oregon State University. Of the 24 students matriculating, 19 completed the required two terms work. The two terms of college work for freshmen was specified in order to give a measure of academic achievement so that this factor could be controlled for in the tests of the null hypotheses.

### Freshmen - Science Education

Freshmen in science education included all students matriculating in science education at the beginning of Fall Term 1964 who completed at least two terms work at Oregon State University. Forty-one of the forty-nine students who started on a program in science education completed at least two terms work. Twice as many freshmen students matriculated in science education as in social science education. Whereas the freshmen women outnumbered the freshmen men in social science education by about two to one, the ratio of men to women in science education was about equal. The ratio of men to women was approximately the same for science teacher-candidates as it was for science education freshmen.

### Elementary Teacher-Candidates

Elementary teacher-candidates included all students taking elementary science and mathematics methods courses during Fall Term 1964 for whom Scholastic Aptitude Test scores were available. These scores were available for all freshmen students and for all teacher-candidates who enrolled as freshmen at Oregon State since Fall Term 1961, but they were not available for students who enrolled as freshmen at Oregon State University prior to that date or for students who began their college education at other institutions. Of the 58

students enrolled in elementary science and mathematics methods classes during Fall Term, Scholastic Aptitude Test scores were available for 31. Only 2 of the 31 were men.

#### Social Science Teacher-Candidates

Social science teacher-candidates were defined as students enrolled in social science education at Oregon State University who completed their social science methods course during the 1964-65 academic year and for whom Scholastic Aptitude Test scores were available. Of the 25 to whom criterion tests were administered, 18 met this requirement. Two-thirds of the social science teacher-candidates were men.

#### Science Teacher-Candidates

Science teacher-candidates were defined as students enrolled in a science education curriculum at Oregon State University who registered for a special secondary science or mathematics methods course during the 1964-65 academic year and for whom Scholastic Aptitude Test scores were available. Of the 66 students to whom criterion tests were administered, 36 met this requirement. As in the case of the other teacher-candidates, a large number of students who might otherwise have been considered as teacher-candidates had entered Oregon State University prior to Fall Term 1961 when

Scholastic Aptitude Tests were first administered at this institution, or had transferred from other institutions of higher education.

Nearly half of the science teacher-candidates were men.

#### In-Service Science Teachers

In-service science teachers consisted of high school science and mathematics teachers who were participants in the 1964-65 Academic Year Institute at Oregon State University. This group was included in the study in order to compare science and mathematics teacher-candidates at Oregon State University with a select group of experienced science and mathematics teachers. The requirement that this group consist of American citizens eliminated 2 of the 47 members to whom the criterion tests were administered. Three others failed to complete the Scholastic Aptitude Test which was administered to this group during new student week prior to the beginning of Fall Term 1964. The resulting group of 42 individuals consisted of 36 men and six women.

Data relative to the total number of students in each group and the relative number of men and women are summarized in Table I.

#### Academic Standings of the Population

Both groups of freshmen students were well defined academically in that no student had completed any college work prior to the

Table I. Numbers and Percentage by Sex of Freshmen, Teacher-Candidates and In-Service Science Teachers

Group	n	Men		Women	
		n	%	n	%
Freshmen - Social Science Education	19	7	36.8	12	63.2
Freshmen - Science Education	41	21	51.2	20	48.8
Elementary Teacher-Candidates	31	2	6.5	29	93.5
Social Science Teacher-Candidates	18	12	66.7	6	33.3
Science Teacher-Candidates	36	17	47.2	19	52.8
In-Service Science Teachers	42	36	85.7	6	14.3

Table II. Academic Standings of Freshmen, Teacher-Candidates and In-Service Science Teachers

Group	n	Academic Standing				
		Fr.	Soph.	Jr.	Sr.	Grad
Freshmen - Social Science Education	19	19	0	0	0	0
Freshmen - Science Education	41	41	0	0	0	0
Elementary Teacher-Candidates	31	0	0	10	21	0
Social Science Teacher-Candidates	18	0	0	4	13	1
Science Teacher-Candidates	36	0	0	8	28	0
In-Service Science Teachers	42	0	0	0	0	42

administration of the criterion tests. As shown in Table II, the in-service science teachers, all of whom had completed at least three years of teaching, had completed baccalaureate degrees and were in various stages of completing graduate programs. The groups of teacher-candidates were less homogeneous--each including junior and senior students. Whereas the social science and science teacher-candidates consisted of juniors and seniors in ratios of about one to three, the ratio of juniors to seniors was nearly one to two for the elementary teacher-candidates.

### The Evaluation Instruments

#### Scholastic Aptitude Test

The Scholastic Aptitude Test was selected to control statistically for the scholastic aptitude of the subjects of this study. This test was professionally administered to candidates for college entrance, and has been widely used as a predictor of academic success in college.

The test consisted of five sections, each 30 minutes in length. The first three, containing mixtures of completion items, opposites, analogies and paragraph comprehension exercises, were scored together as a verbal subtest. The last two, designated as Arithmetic Reasoning although they included considerable algebra and elementary

geometry, were scored as a mathematical subtest. Standard scores were available separately for the two subtests.

A tremendous amount of normative and analytical data regarding the test has been published in the manuals. Dailey (23, p. 319), in reviewing this test, considered it to be:

... essentially a conventional general abstract "intelligence" test at the bright adult level. It does a very effective job of estimating liberal arts scholarship potential.

In another review, Davis (25, p. 268) stated:

The validity data indicate that this test is about as useful for predicting academic success as a test of its limited scope can be. ... one can be reasonably sure that the examinee will not have had access to it beforehand and that it will be administered and scored with scrupulous care and accuracy.

Factors relating to the choice of this test as an instrument for measuring "intelligence" were: (a) it has been widely used and came highly recommended for use with college students, (b) the investigator could not justify the expenditure of student time to administer a test of comparable comprehensivity, and (c) the Scholastic Aptitude Test scores were already available for a major portion of the subjects of this study. The combined verbal and mathematical, SAT (V-M), scores for each subject were used as a covariance control for "intelligence" in the tests of the null hypotheses.

## Cornell Critical Thinking Test

The Cornell Critical Thinking Test, Form X, was selected to evaluate student critical thinking ability. Form X, an experimental edition copyrighted in 1961, consisted of 71 multiple choice items divided into four subtests designed to reveal how well the student was able to correctly assess statements. Four aspects of critical thinking measured by these subtests were: (a) Induction: evaluation of evidence for or against a hypothesis, 23 items; (b) Reliability: evaluation of the reliability of information, 24 items; (c) Deduction: logical reasoning ability, 14 items; and (d) Assumption-finding: recognition of assumptions, ten items. Separate answer sheets were provided with reusable test booklets. Time for administration was 50 minutes.

Ennis, author of the test, has rather precisely defined critical thinking as follows (36, p. 599):

As a root notion, critical thinking is here taken to mean the correct assessing of statements. ... if we set about to find out what a statement means to determine whether to accept or reject it, we would be engaged in thinking, which, for lack of a better term, we shall call critical thinking.

A critical thinker is characterized by proficiency in judging whether:

1. A statement follows from the premises.
2. Something is an assumption.
3. An observation statement is reliable.
4. A simple generalization is warranted.
5. A theory is warranted.

6. An argument depends on an ambiguity.
7. A statement is overvague or overspecific.
8. An alleged authority is reliable.

In order to develop an operational definition of critical thinking for the purpose of designing a measuring instrument, the following important aspects of critical thinking were deliberately excluded (36, p. 600): (a) The judging of value statements; (b) Creative thinking; and (c) Judging whether a problem has been identified. Several aspects of critical thinking which are measured by the Cornell Critical Thinking Test have been amplified by Ennis (36, p. 604) as follows:

Judging whether a hypothesis is warranted. A hypothesis is warranted to the extent that:

1. It explains a bulk and variety of reliable data.
2. It is itself explained by a satisfactory system of knowledge.
3. It is not inconsistent with any evidence.
4. Its competitors are inconsistent with the evidence. This is the basis of controlled experiments.
5. It is testable. It must be, or have been, possible to make predictions from it.

Judging whether an observation statement is reliable. Observation statements tend to be more reliable if the observer:

1. Was skilled at observing the sort of thing observed.
2. Had good sensory equipment in good condition.
3. Has a reputation for veracity.
4. Used precise techniques.
5. Had no preconception about the way the observation would turn out.

The above statements provide examples of the preciseness with

which aspects of critical thinking have been defined by the author of the Cornell Critical Thinking Test. Several of the foregoing statements of aspects of critical thinking are consistent with generally accepted objectives of science education which are commonly listed as components of the scientific method.

General agreement between concepts of critical thinking measured by this test and those measured by other critical thinking tests analyzed by Dressel (29) and Rust (77) supports the validity of the criterion instrument. The previously mentioned consistency between generally accepted objectives of science education and the rather precisely defined aspects of critical thinking measured by the Cornell Critical Thinking Test, constitutes additional evidence of the validity of this test for use with science students. The critical thinking abilities measured by this test are also consistent with statements of critical thinking competencies desired for social science students (3, 29). These factors were influential in the investigator's choice of the criterion test used to measure critical thinking abilities of the participants in this study.

No manual having been prepared to accompany the experimental edition of the CCTT, the author of the test supplied some standardization data based upon administration of the test to seventh and eighth grade students. Although quite limited, the data relative to the split-half reliability estimate does indicate an acceptable reliability level

(.85 and .89) for the Cornell Critical Thinking Test, Form X.

Moderate positive coefficients of correlation between this test and those of mental ability (.39 and .49), and scholastic aptitude (between .49 and .61), indicate that this critical thinking test measures thinking abilities different from those measured by mental ability and scholastic aptitude tests.

#### Test on Understanding Science

The Test on Understanding Science, Form W, was developed by Cooley and Klopfer (21) at the Harvard University Graduate School of Education. This instrument was selected to measure the understandings of science of the students who participated in this study.

Form W (TOUS), published by Educational Testing Service in 1961, consists of 60 multiple choice items which were designed to reveal student understanding in three areas of science. These were defined by Cooley and Klopfer with the counsel of science educators, science teachers, and numerous professors of science and the history and philosophy of science. Separate answer sheets were provided with reusable test booklets. Time for administration was 40 minutes.

Following is a summary of the areas for which specifications were developed as a basis for TOUS (21, p. 3):

Area I - The Scientific Enterprise; 18 items. This area included seven themes which were identified as:

1. Human element in science.
2. Communication among scientists.
3. Scientific societies.
4. Instruments.
5. Money
6. International character of science.
7. Interaction of science and society.

Area II -The Scientist: 18 items. The themes in this area were:

1. Generalizations about scientists as people.
2. Institutional pressures on scientists.
3. Abilities needed by scientists.

Area III -Methods and Aims of Science; 24 items. In this area, the themes were:

1. Generalities about scientific methods.
2. Tactics and strategy of sciencing.
3. Theories and models.
4. Aims of science.
5. Accumulation and falsification.
6. Controversies in science.
7. Science and technology.
8. Unity and interdependence of the sciences.

The Manual for Administering, Scoring and Interpreting TOUS

Scores provides standardization data obtained in a study involving 2535 high school science students (21, p. 10). Using total test scores, reliability was determined as .76 by applying the Kuder-Richardson Formula 20 to test data from the 2535 students. For Areas I, II, and III the reliabilities were calculated as .58, .52, and .58 respectively.

As previously noted, several consultants were used to provide a check upon the content validity of TOUS and the validity of the themes upon which TOUS is based. A preliminary form of this test was used in a small study carried out in the summer of 1960 with a group of 78 talented high school students in two summer programs. In both of these programs, the students were in active contact with working scientists. Using a pre-test, post-test technique, it was found that students in both groups made significant changes toward the desired "correct" responses to items on TOUS (21, p. 6). A similar group of students not participating in such a program did not tend to move toward the "correct" responses.

The relation of TOUS to general scholastic aptitude was investigated by administering the Otis Mental Ability Test, Form Am, at the same time that TOUS was given to 2980 high school students in October, 1960. For students in grades 9 through 12 the product moment correlations ranged from .64 to .69. From these data, it may be concluded that while there is a moderate positive

correlation between mental ability and understanding of science, TOUS and the Otis Mental Ability Tests measure different things.

### Procedures Used in Collecting the Data

#### Criterion Test Scores

The Cornell Critical Thinking Test and the Test On Understanding Science were administered to the science education freshmen and to the in-service science teachers at separate testing sessions held during New Student Week, prior to the beginning of the 1964 Fall Term, at Oregon State University. Special testing sessions were held during the third week of Fall Term to administer criterion tests to freshmen in social science education. Students registered for the elementary science and mathematics methods courses were tested during Fall Term at special sessions which were arranged with instructors of the courses. A similar procedure was followed in administering criterion tests during both Fall and Spring Terms to students in special secondary methods courses in social science, biological science, physical science, general science, and mathematics. Tests were administered according to directions provided in the Manual for Administering, Scoring and Interpreting Scores of the Test on Understanding Science (21) and according to directions printed on each of the criterion tests.

### Scholastic Aptitude Test Scores

Scholastic Aptitude Test scores for freshmen students in social science education and science education were obtained from their respective advisers during the first two weeks of Fall Term. These scores were obtained for teacher-candidates from college transcripts, acquired from the Office of the Registrar at Oregon State University during the term that the teacher-candidates were identified by registering for their respective special methods courses. Verbal and mathematical subtests of the Scholastic Aptitude Test were administered to the in-service science teachers at a regularly scheduled administration of this test during New Student Week. All Scholastic Aptitude Tests were professionally administered and scored according to College Entrance Examination Board Specification.

### Academic Records

The academic records of each student were examined and data compiled with reference to the following factors which were thought to be related to achievement on the criterion instruments:

1. Accumulative university grade point average.
2. Total number of credits (quarter hours) completed in:
  - a. Biological sciences.

- b. Physical sciences.
- c. Mathematics.
3. Grade point average for biological and physical science courses completed.
4. High school grade point averages and high school credits earned in science and mathematics.

#### Statistics Utilized in Analysis of Data

In-service science teachers, three groups of teacher-candidates, and two groups of freshmen entering teacher preparation programs at Oregon State University were evaluated during the 1964-65 academic year with respect to critical thinking abilities and understandings of science.

General scholastic aptitude was measured by verbal and mathematical subtests of the Scholastic Aptitude Test administered to the in-service science teachers, represented by Academic Year Institute Participants, prior to the beginning of Fall Term 1964. Students in the other groups had taken these tests prior to beginning their respective freshman years at Oregon State University. The sum of the verbal and mathematical subtest scores, SAT (V + M), was computed for each student. This combined score was used to control for student differences in scholastic aptitude in tests of the null hypotheses.

Accumulative college grade point averages, taken from transcripts obtained from the Office of the Registrar at Oregon State University or from the Director of the Academic Year Institute, were used as measures of academic achievement. Critical thinking abilities were assessed by the Cornell Critical Thinking Test, Form X. Understandings of science were sampled by the Test on Understanding Science, Form W.

Group means, rather than individual student scores, were used as the unit of analysis, since it was the participating groups, not the individual students, which had been subjected to curricular variations which were compared. Group means were calculated for the tests administered and for data taken from college transcripts. The group mean for each test was computed by totaling the raw scores for the group and dividing by the number of students.

Standard deviations were computed for the data used in testing the null hypotheses. This measure of variability was computed for ungrouped data according to the procedure outlined by Wert (93, p. 56). Distributions of Scholastic Aptitude Test scores were compared with distributions which would be expected if the scores were representative of a normal distribution. The procedure described by Wert (93, p. 63) was followed in making this comparison. Pearson product-moment coefficients of correlation between each of the criterion test scores and several aptitude and curricular variables

were calculated for each group.

In the tests of the null hypotheses, means of the science teacher-candidates for each of the criterion tests were compared to means of freshmen in social science education, science education freshmen, elementary teacher-candidates, social science teacher-candidates, and in-service science teachers. Since scores on such tests are usually correlated with general scholastic aptitude and to academic achievement, a suitable statistical design is a single classification analysis of covariance. Analysis of covariance is recommended by Wert (93, p. 343):

To provide the investigator with a means of attaining a measure of control of individual differences... if... individual differences among the members within the group are either known to influence the criterion or suspected of such influence.

Regression equations were calculated for total and for within the subgroups. The F ratios were computed by using the adjusted within mean square as the denominator in each case. A table (93, p. 419) giving the five and one percent values of F ratios was consulted in order to determine the level of significance of differences of group means on criterion tests. Mean criterion test scores of several subgroups of science teacher-candidates were also compared, using analysis of covariance in order to determine if differences were statistically significant.

Chi square was used in order to determine if variations of

group responses to selected items from the Test on Understanding Science were greater than would be expected as a result of sampling fluctuation. A method of computing chi square in an  $R \times 2$  table, as outlined by Snedecor (81, p. 205), was utilized for this purpose.

The investigator received advice from Dr. Lyle Calvin, Chairman of the Statistics Department at Oregon State University, concerning the statistical design of this study.

### Processing of the Data

Data from the various sources were tabulated on data sheets, then punched on IBM cards for analysis. Using the statistical designs cited in the previous section, the investigator wrote, punched and tested programs for execution on the IBM 1620 computer. Programs were designed to compute means, standard deviations, coefficients of correlation and F ratios used in this study. Chi squares were computed using a desk calculator.

At the suggestion of Mr. Thomas Yates, Director of the Statistics Computing Laboratory at Oregon State University, the programs designed by the investigator for execution on the IBM 1620 computer were converted to be executed on the higher speed IBM 1410 computer. The revision consisted primarily of altering read-in and print-out instructions to the computer. These programs were executed at the Oregon State University Computing Laboratory using

data cards supplied by the investigator. At least one calculation of the computer output for each equation was checked on the desk calculator or on the computer using a tested data deck in order to assure accuracy of the computer program.

### Limitations of the Study

Effects of a planned curriculum in teacher education on the development of critical thinking abilities and understandings of science have been investigated. Hypotheses that mean group differences in these abilities and understandings, as measured on the criterion instruments, may have resulted from group variations in general intelligence and academic aptitude were statistically controlled using the covariance technique.

The hypothesis that factors other than planned curricula, general intelligence, and academic aptitude may have affected the group mean criterion test scores, was not tested in this study. For example, the groups may have been subjected to different formal and informal learning situations which were not considered in this study, but which affected the test results.

Critical thinking is generally agreed to be a relatively complex process. The criterion instrument used to measure critical thinking was designed to measure selected aspects of this ability. Other important aspects of critical thinking, which may have been outcomes

of curricula studied, were not examined. A comparable situation existed for understandings of science.

The study was confined to relatively small groups of students at a single university. This fact limits the extent to which the findings can be generalized.

## CHAPTER IV

## PRESENTATION AND INTERPRETATION OF THE FINDINGS

This study was undertaken in order to determine the comparative effects of several curricula which were designed specifically for the education of teacher-candidates, on their attainment of critical thinking abilities and selected understandings of science. Science teacher-candidates were compared in critical thinking ability and understanding of science to (a) freshmen matriculating in social science education, (b) freshmen matriculating in science education, (c) elementary teacher-candidates, (d) social science teacher-candidates, and (e) in-service science teachers represented by Academic Year Institute Participants. The investigation was conducted at Oregon State University during the 1964-65 academic year. The subjects were all students at Oregon State University during the period of the investigation.

Data were obtained through: (a) single administrations of the instruments selected to measure aspects of critical thinking ability and understandings of science, and (b) analyses of student records obtained from the Office of the Registrar or the Office of the Academic Year Institute Director at Oregon State University. Data secured from these sources were tabulated on data sheets then punched on IBM cards for processing.

The data collected in this study were used in two series of statistical analyses: (a) the analyses of the data in which group means, standard deviations, and correlations between criterion test scores and several variables for each group of participants were compared; and (b) testing of the null hypotheses.

In the tests of the null hypotheses, the statistical model employed was the single classification analysis of covariance. Group means, rather than individual student scores, were used as the unit of analysis, since it was the participating groups, not the individual students which were being compared.

The null hypotheses under test have been stated in Chapter I and will be reviewed in this chapter when tests of the hypotheses are examined. The criterion measure in each of the tests of the hypotheses was either the group mean on the Cornell Critical Thinking Test or the group mean on the Test on Understanding Science. Group means of (a) the sum of verbal and mathematical subtest scores of the Scholastic Aptitude Test, and (b) accumulative college grade point averages were applied as covariance controls to the CCCT and TOUS group means.

### Analyses of the Data

#### Non-Criterion Variables of the Participating Groups

This section is concerned with the following factors which the

investigator hypothesized to be related to the group means on the criterion instruments:

1. General academic achievement in high school and college as measured by accumulative grade point averages.
2. The number of high school and college credits earned in biological science, physical science, and mathematics.
3. Scholastic aptitude as measured by the verbal and mathematical subtests of the Scholastic Aptitude Test.

#### High School Achievement and High School Science Preparation.

Although the primary concern of this study dealt with the effect of college curricula on the development of critical thinking abilities and understandings of science by teacher-candidates, it was considered important to investigate the mean high school grade point average and the mean number of high school science credits completed by the students in each group because (a) students in two of the groups which participated in the study had just completed their high school education and had not begun their college education, (b) this provided a common basis for comparing freshmen and teacher-candidates in both science education and social science education, and (c) these same factors, at the college level, were variables in the tests of the null hypotheses.

Table III reveals a marked similarity between science education

freshmen and science teacher-candidates with respect to both high school grade point averages and the number of high school science credits completed. A similar observation may be made between freshmen and teacher-candidates in social science education. Both the freshmen and teacher-candidates in science education had higher high school grade point averages, and had completed more high school science credits than had the freshmen and teacher-candidates in social science education. Evidence that this same difference occurred at the college level, is shown in Table IV.

Table III. Mean Number of High School Credits Earned in Science and Mathematics, and Mean High School Grade Point Averages of Freshmen and Teacher-Candidates

Group	n	H. S. GPA	High School Science Credits		
			Biol.	Chem. Phys.	Math.
Freshmen - Social Science Education	19	3.25	1.2	1.4	3.2
Freshmen - Science Education	41	3.27	.9	1.6	3.8
Elementary Teacher- Candidates	31	2.93	.8	.9	2.9
Social Science Teacher-Candidates	18	2.78	.8	1.2	2.8
Science Teacher- Candidates	36	3.44	1.8	1.8	3.8

While the participating groups varied in the mean number of high school science credits completed, this variation, which amounted to one credit or less, is quite small as compared to that at the college

level, which, as Table VI will show, amounts to as much as 34 term hours. Due to the relative similarities between high school and college grade point averages for each group, and the relatively small variations in the number of high school science credits completed as compared to the number of quarter hours of college science completed by each group, the high school data were not used in any further analyses.

Group Means on the Covariance Controls. Comparisons of SAT (V + M) group means in Table IV disclosed that marked similarities existed between freshmen and teacher-candidates in both social science education and science education. While mean group differences between freshmen and teacher-candidates amounted to less than 13 points for both social science and science education students, mean group differences between freshmen in social science education and science education amounted to over 92 points and mean group differences between social science and science teacher-candidates amounted to 95 points. Of all the groups participating in the study, SAT (V + M) means were lowest for elementary teacher-candidates (912.48), and highest for in-service science teachers (1226.12). The SAT (V + M) standard deviations were relatively large (174.85) for science education freshmen and relatively small (136.00) for science teacher-candidates, indicating that the latter

group was more homogenous with respect to scholastic aptitude than was the former.

Table IV. Mean Scholastic Aptitude Test Scores and Mean College Grade Point Averages of Freshmen, Teacher-Candidates and In-Service Science Teachers

Group	n	SAT (V + M)		College GPA	
		Mean	S. D.	Mean	S. D.
Freshmen - Social Science Education	19	983.89	135.29	2.34*	.45
Freshmen - Science Education	41	1076.02	174.85	2.45*	.54
Elementary Teacher-Candidates	31	912.48	141.93	2.59	.41
Social Science Teacher-Candidates	18	993.44	145.11	2.66	.40
Science Teacher-Candidates	36	1088.67	136.00	2.88	.40
In-Service Science Teachers	42	1226.12	175.80	3.05**	.33

\* Based on two terms work at Oregon State University.

\*\* Based on all college work completed prior to beginning of Academic Year Institute.

SAT (V + M) = Sum of verbal and mathematics scores on Scholastic Aptitude Test.

Mean accumulative college grade point averages in Table IV show that substantial differences existed between freshmen and teacher-candidates for both social science students (.32 grade point) and science education students (.43 grade point). This may reflect

self-elimination of the less capable students which begin teacher education programs. Among the groups of teacher-candidates, mean accumulative college grade point averages increased with increasing SAT (V + M) means. The mean college GPA of the elementary teacher candidates was lowest (2.59), while that of the science teacher-candidates was highest (2.88). The high mean and small standard deviation of the grade point average of the in-service science teachers, indicated this to be a relatively select homogeneous group with respect to academic achievement.

Distributions of SAT (V + M) scores of the freshmen, the teacher-candidates, and the in-service science teachers were compared to each other and to expected frequencies of a normal curve. These comparisons, shown in Table V, reveal that the distribution of scores of both social science freshmen and social science teacher-candidates were skewed to the higher scores. Those of the science education freshmen and elementary teacher-candidates were slightly skewed to the lower scores. The distribution of SAT (V + M) scores of science teacher-candidates closely fits the frequencies expected for a normal curve. Although the percentage of scores above and below the mean for the in-service science teachers were approximately equal, the distribution was unusual in terms of the large number of scores between  $-2\sigma$  and  $-3\sigma$  and the low number of scores between  $-1\sigma$  and  $-2\sigma$ . Distributions of SAT (V + M) scores of all

Table V. Comparison of Expected Frequencies of a Normal Curve and Distribution of SAT (V + M) Scores of Freshmen, Teacher-Candidates and In-Service Science Teachers

Expected Frequency	-3 $\sigma$	-2 $\sigma$	-1 $\sigma$	Mean	+1 $\sigma$	+2 $\sigma$	+3 $\sigma$
	2%	14%	34%	34%	14%	2%	
Freshmen - Social Science Education	0.0%	15.9%	31.4%	31.4%	15.9%	5.4%	
Freshmen - Science Education	4.9%	12.2%	34.1%	31.7%	14.6%	2.4%	
Elementary Teacher-Candidates	3.2%	9.7%	45.0%	29.0%	6.5%	6.5%	
Social Science Teacher Candidates	5.6%	11.1%	27.8%	38.9%	16.6%	0.0%	
Science Teacher-Candidates	2.8%	13.9%	33.2%	33.2%	13.9%	2.8%	
In-Service Science Teachers	7.1%	4.7%	38.1%	33.4%	16.6%	0.0%	

SAT (V + M) = Sum of verbal and mathematical subtest scores on Scholastic Aptitude Test

the groups which participated in the study approximate the frequencies expected of a normal curve.

College Achievement and Science Preparation. Knowledge that curricula specifically designed to prepare elementary, social science, and science teachers at Oregon State University varied considerably with respect to science requirements suggested to the investigator that these three groups of teacher-candidates be compared in order to assess group differences in critical thinking abilities and understandings of science. The data summarized in Table VI shows that differences did exist in the amount and type of science studied by the different groups of teacher-candidates who participated in this study. Data for the in-service science teachers is included for comparative purposes.

Although the science grade point averages for each group are lower than the previously mentioned grade point averages over all college course work completed, this difference amounts to less than 0.05 grade points for both the science teacher-candidates and the in-service science teachers. This small difference between overall GPA and science GPA may have reflected a relatively high science interest and aptitude of the students in these two groups. These students had successfully completed a relatively large number of science courses. The greatest variation, 0.42 grade points, between overall

Table VI. Mean Science Grade Point Average and Mean Number of Quarter Hours of Science Completed by Teacher-Candidates and In-Service Science Teachers

Group	n	Science GPA	Hours in Science*	Hours in Biological Science	Hours in Physical Science	Hours in Mathematics
Elementary Teacher-Candidates	31	2.17	13.2	7.9	5.3	6.5
Social Science Teacher-Candidates	18	2.39	24.5	16.6	7.9	6.6
Science Teacher-Candidates	36	2.86	48.0	21.3	26.8	27.2
In-Service Science Teachers	42	3.00	79.5	29.6	49.9	30.2

\* Sum of quarter hours earned in biological sciences and physical sciences.

GPA and science GPA was observed for the elementary teacher-candidates. These students, as a group, had completed the least amount of work in science.

A ratio of approximately 1 : 2 : 4 : 6 was found when the mean number of total quarter hours of science completed by elementary teacher-candidates, social science teacher-candidates, science teacher-candidates, and in-service science teachers were compared in that order. While the elementary teacher-candidates had completed about equal numbers of credits in biological science, physical science, and mathematics, the total was less than 20 quarter hours. Social science teacher-candidates differed in science preparation from the elementary teacher-candidates primarily in that they had completed approximately twice as many quarter hours of biological science. Science teacher-candidates and in-service science teachers were characterized by having completed more work in each of the science areas with greater emphasis in the physical sciences and mathematics than in the biological sciences. Group variations in college science preparation are shown in Table VI.

#### Critical Thinking Ability of the Subjects

Subtest and total test means on the Cornell Critical Thinking Test for each participating group are shown in Table VII. It is clear from this data that the groups differed in critical thinking ability as

Table VII. Comparison of Critical Thinking Subtest and Total Test Means for Freshmen, Teacher-Candidates, and In-Service Science Teachers

Group	n	Cornell Critical Thinking Subtest				CCTT Total (71 items)		
		I, A	I, B	II, A	II, B	Mean	S. D.	Variation
Freshmen - Social Science Education	19	16.58	15.74	11.58	5.42	50.32	4.92	-5.15
Freshmen - Science Education	41	17.11	16.13	12.52	5.69	52.46	6.04	-3.01
Elementary Teacher-Candidates	31	15.58	15.55	11.26	5.58	48.97	6.21	-6.50
Social Science Teacher-Candidates	18	16.40	17.01	12.46	6.29	53.17	5.86	-2.30
Science Teacher-Candidates	36	17.05	18.08	12.78	6.55	55.47	5.58	0.00
In-Service Science Teachers	42	15.85	17.52	12.78	6.78	53.93	7.01	-1.54

\*Variation = Variation from CCTT mean of science teacher-candidates.

Part I, Section A = Induction (23 items). Evaluation of evidence for or against a hypothesis.

Part I, Section B = Reliability (24 items). Evaluation of the reliability of information.

Part II, Section A = Deduction (14 items). Logical reasoning.

Part II, Section B = Assumption-Finding (10 items). Recognition of assumptions.

measured by this test. Although the group means differed by less than three points on all of the subtests, three groups--the social science freshmen, the science education freshmen, and the elementary teacher-candidates--had total mean scores which were more than three points lower than the highest group mean which was attained by the science teacher-candidates.

The fact that differences in group means for the total test score were greater than were the subtest differences for the same group of students, indicated that each of the subtests contributed to the total critical thinking score of the group. This is supported by the general agreement between group subtest and total scores which is observed in Table VII.

On both the induction and deduction subtests, science education freshmen differed little on group CCTT means from the science teacher-candidates. A similar observation was made for the two groups of social science students. Differences between freshmen and teacher-candidates in both science and social science were more substantial on the reliability and assumption-finding subtests, however. In both instances the differences were in favor of the teacher-candidates. The elementary teacher-candidates scored lowest of all the groups on all subtests except the one on assumption-finding. The in-service science teachers differed least from the science teacher-candidates on both subtest and total test scores. The major

difference between these two groups was on the induction subtest on which the teacher-candidates outscored the in-service teachers by 1.20 points. A comparison of the standard deviations of the CCTT total scores revealed that these scores for the in-service science teachers varied more than did those of any other group.

Coefficients of correlation between Cornell Critical Thinking Test scores and each of several variables for students in each of the participating groups are shown in Table VIII. No correlations were calculated between CCTT scores and science GPA, hours in science, or science grade point totals for the freshmen groups because these variables for the freshmen were too small to be meaningful.

A table of  $r$  at the five and one percent levels of significance was consulted (93, p. 424) in order to determine whether the correlations were statistically significant. If the correlations were significant at either the one or five percent level, it was concluded that the correlation was too large to be due to chance alone.

Correlations were observed to be highest between CCTT scores and SAT (V + M), SAT (V), and SAT (M) scores in that order. Correlations between SAT (V + M) and CCTT scores were significant at the five percent level of confidence for five of the six groups in the study.

Only one of the group correlations between CCTT total scores and either accumulative GPA or science GPA was significant at the five

Table VIII. Correlations Between Individual Scores on the Cornell Critical Thinking Test and Several Variables for Freshmen, Teacher-Candidates, and In-Service Science Teachers

Group	n	Criterion Test	S A T (V+M)	Accum. G P A	S A T (V)	Science GPA	S A T (M)	Hours in Science	Science Grade Point Total
Freshmen - Social Science Education	19	<u>CCTT</u>	.43**	.30	.49**	--	.20	--	--
Freshmen - Science Education	41	<u>CCTT</u>	.68**	.15	.66**	--	.60**	--	--
Elementary Teacher - Candidates	31	<u>CCTT</u>	.25	.31	.34	.39*	.12	-.25	-.09
Social Science Teacher-Candidates	18	<u>CCTT</u>	.56*	-.05	.27	.00	.65**	-.01	-.10
Science Teacher- Candidates	36	<u>CCTT</u>	.42*	.18	.32	.13	.32	-.08	-.43*
In-Service Science Teachers	42	<u>CCTT</u>	.60**	.10	.70**	.05	.44**	-.12	-.15

\*Indicates that the correlation is significant at the five percent level.

\*\*Indicates that the correlation is significant at the one percent level.

percent level. Negative correlations were observed between CCTT total scores and the total number of college science credits earned by students in each group. CCTT total scores also correlated negatively to the total number of science grade points earned by students in each group. The only negative correlation which was statistically significant, however, was that between CCTT scores and science grade point totals for science teacher-candidates. This group had not only completed a relatively large number of science courses with relatively high grade point averages, but had quite recently completed this work.

Summary. Group differences as great as six and one-half points were observed on group CCTT total means. Science teacher-candidates group means were highest followed by those of in-service science teachers and social science teacher-candidates, in that order. The elementary teacher-candidate CCTT mean was lower than that for any of the other groups.

While group means on CCTT subtests varied, the variations were relatively small. The subtest means all appeared to contribute, however, to the group total CCTT means. The Cornell Critical Thinking Test mean was significantly correlated (at the five percent level) to SAT total and subtest scores for a majority of the groups.

Correlations between CCTT total group means and both accumulative grade point averages and science grade point averages were non-significant for all groups. For each group, negative correlations were calculated between CCTT scores and both the total number of college science credits completed and the total number of science grade points earned. The only statistically significant negative correlation, however, was between CCTT scores and total number of science grade points earned by science teacher-candidates.

The science courses studied by participants in each of the groups did not appear to have contributed greatly to the development of critical thinking abilities measured by the criterion instrument. The reader is reminded, however, that statistically significant correlations do not constitute cause and effect relationships.

#### Understanding of Science of the Subjects

TOUS subtest and total group means, shown in Table IX, suggest that each of the subtests was consistent in contributing to observed differences in total TOUS group means. The only exception to this consistency was subtest II on which the freshmen in social science education scored higher than did the science education freshmen.

Total TOUS group means, which ranged from 36.00 to 47.21, evidenced considerable variation among the groups in understandings

Table IX. Comparison of Understanding of Science Subtest and Total Test Means for Freshmen, Teacher-Candidates, and In-Service Science Teachers

Group	n	TOUS Subtests			TOUS Total (60 items)		
		Area I	Area II	Area III	Mean	S. D.	Variation*
Freshmen - Social Science Education	19	11.21	12.58	12.21	36.00	4.55	-10.31
Freshmen - Science Education	41	11.76	12.17	13.10	37.02	6.27	- 9.29
Elementary Teacher-Candidates	31	12.75	12.62	14.46	39.84	3.96	- 6.47
Social Science Teacher-Candidates	18	13.56	13.83	15.17	42.56	5.98	- 3.75
Science Teacher-Candidates	36	14.50	14.20	17.61	46.31	4.77	0.00
In-Service Science Teachers	42	15.17	14.48	17.57	47.21	4.81	+ 0.90

\*Variation = Variation of group mean TOUS score from that of science teacher-candidates.

Area I - The Scientific Enterprise (18 items).

Area II - The Scientist (18 items).

Area III - Methods and Aims of Science (24 items).

of science as measured by this instrument. Freshmen in social science education, having a mean total score of 36.00, had understandings which differed most from those accepted as the best answers on TOUS, while the in-service science teachers were highest in agreement with the accepted responses. Their mean was 47.21.

Subtest and total TOUS scores for science teacher-candidates showed close agreement to those of the in-service science teachers. A wide variation within the group of science education freshmen was revealed by the relatively large standard deviation of 6.27 points on total TOUS scores. The elementary teacher-candidates, with a standard deviation of 3.96, varied least of all the groups on TOUS.

The group mean TOUS scores of the participants in this study compared favorably to those reported by Klopfer (60) for an experimental study which was designed to determine the effect of the use of history of science case studies on understandings of science measured by TOUS. In Klopfer's study, the high scoring experimental subgroups in biology, chemistry, and physics had post-test group means of 36.63, 38.19, and 37.00 respectively. For the entire group of 2,590 students in the study, the TOUS group means of the biology students was 35.54. For chemistry students it was 35.54, and for physics students, 35.69.

On the basis of Klopfer's data for a relatively large group of students which included representatives from small, medium and large public

and private schools that were widely distributed geographically, this investigator concluded that the mean understandings of science by the science teacher-candidates and in-service science teachers who participated in this study were superior to the mean understandings of groups of high school students whom they are likely to teach.

Coefficients of correlation between total scores on the Test on Understanding Science and each of several variables, including the Cornell Critical Thinking Test, are shown in Table X. A table of values of  $r$  at the five and one percent levels of significance (93, p. 424) was consulted in order to determine whether the computed correlations were statistically significant.

While correlations between TOUS and CCTT scores were significant at the five percent level for both groups of freshmen and the in-service science teachers, they were not significant for any of the groups of teacher-candidates. TOUS scores showed correlations to both SAT (V + M) and SAT (V) scores which were statistically significant at the one percent level for four of the six groups.

With one exception, a correlation, significant at the five percent level, was noted between TOUS scores and both accumulative GPA and science GPA for each of the groups. As was the case for CCTT scores, the number of term hours of science completed was not significantly correlated to TOUS scores. Similarly, the non-significant and the negative correlations between TOUS scores and the total

Table X. Correlations Between Individual Scores on the Test on Understanding Science and Several Variables for Freshmen, Teacher-Candidates and In-Service Science Teachers

Group	n	Criterion Test	C C T T	S A T (V+M)	Accum. G P A	S A T (V)	Science GPA	S A T (M)	Hours in Science	Science Grade Point Total
Freshmen - Social Science Education	19	<u>TOUS</u>	.41**	.46**	.16	.51**	---	.22	---	---
Freshmen - Science Education	41	<u>TOUS</u>	.52**	.72**	.42**	.71**	---	.62**	---	---
Elementary Teacher- Candidates	31	<u>TOUS</u>	.28	.32	.64**	.36	.53**	.22	-.24	-.01
Social Science Teacher-Candidates	18	<u>TOUS</u>	-.02	.43	.70**	.52*	.65**	.18	.22	.42
Science Teacher- Candidates	36	<u>TOUS</u>	.32	.62**	.43**	.62**	.49**	.31	.22	-.33*
In-Service Science Teachers	42	<u>TOUS</u>	.65**	.65**	.38*	.73**	.35*	.50**	-.01	.08

\* Indicates that the correlation is significant at the five percent level.

\*\* Indicates that the correlation is significant at the one percent level.

CCTT = Cornell Critical Thinking Test

number of science grade points earned did not indicate that, for these students, the study of college science contributed greatly to the development of understanding of science as measured by TOUS total scores.

Summary. Differences as great as 11.21 were observed among the TOUS total group means. The in-service science teachers had the highest group mean, followed by the science teacher-candidates whose mean was 0.9 points lower. Both groups of freshmen scored over nine points lower than did the science teacher-candidates.

TOUS subtest group means indicate that these tests rather consistently contributed to the total group means. The latter were observed to correlate significantly (at the five percent level) to CCTT total scores for in-service science teachers and both groups of freshmen. Significant correlations were found between TOUS and both SAT (V + M) and SAT (V) scores for a majority of the groups.

TOUS scores were significantly correlated to both accumulative and science grade point averages in nine out of ten correlations. The only statistically significant correlation between TOUS totals and either hours in science or science grade point averages, was a negative correlation which was calculated using test scores of the science teacher-candidates.

Development of understandings of science, as measured by

TOUS, did not appear to be a major outcome of the study of college science courses by the participants in this study.

#### Analyses of Specific TOUS Items

Analyses of subtest and total TOUS group means revealed group differences in understandings of science which were relatively consistent from one subtest to another. As groups, both the in-service science teachers and the science teacher-candidates scored higher on all TOUS subtests than did the groups of students who did not plan to teach science. Differences between TOUS subgroup means for the in-service science teachers and the science teacher-candidates were small.

In order to identify the most common misconceptions of science held by the members of each group, the most frequently missed TOUS items were tabulated. Table XI shows TOUS items to which 35 percent or more of the students in each group failed to give the preferred responses. The 35 percent lower limit for the inclusion of items in this table was an arbitrary choice made for convenience of tabulation.

Inspection of Table XI revealed eight items (12, 16, 22, 23, 30, 34, 43, and 46), identified in the Table by underlined item numerals, which were commonly missed by students in all six groups. Examination of these items revealed three groupings of misconceptions

Table XI. TOUS Items Missed by 35 Percent or More of Freshmen, Teacher-Candidates and In-Service Science Teachers

Percent Missing the Item	Freshmen		Teacher-Candidates			In-Service Science Teachers
	Soc. Sci. Education	Science Education	Elementary	Social Science	Science	
80 - 85%	<u>23*</u> , 50	<u>16</u> , <u>43</u> , 50				
75 - 80	<u>43</u>	<u>12</u> , 57	37	<u>22</u>	<u>22</u>	
70 - 75	15, <u>30</u>	<u>34</u>	<u>12</u> , <u>30</u>	<u>30</u> , <u>34</u>		
65 - 70	21, 25		<u>46</u>	<u>46</u>		<u>12</u>
60 - 65	26, 28, <u>34</u> , 37	<u>22</u>	21, <u>22</u> , <u>34</u>	<u>12</u> , 21, <u>23</u> , <u>43</u> , 57	37	
55 - 60	10, <u>16</u> , <u>22</u> , 39 <u>46</u> , 52, 57, 59	15, <u>23</u> , <u>46</u> , 56	<u>16</u> , <u>23</u> , 50	7	<u>12</u> , <u>34</u>	<u>16</u> , <u>34</u>
50 - 55	7, <u>12</u> , 55	10, 28, <u>30</u> , 37 39	29	10, <u>16</u> , 28, 56	50	<u>22</u> , <u>23</u>
45 - 50	18, 49, 56	28, 29, 47, 49 55, 59	25, <u>43</u> , 57	25	<u>16</u> , <u>23</u> , <u>30</u>	57
40 - 45	20, 32	19, 20, 25, 32	7, 10, 26, 33, 52	26, 37, 39 50, 58	<u>43</u> , <u>46</u> , 57	
35 - 40	33, 54	7, 21, 26, 33, 52, 58	9, 19, 20, 56		10, 21, 55, 59	10, 15, 21, 37 <u>43</u> , <u>46</u>

\* Underlined numerals indicate TOUS items analyzed in the text of the study.

of science and scientists which the investigator considered to have implications for the education of science teachers. These groupings were (a) personal characteristics of scientists, (b) distinction between science and technology, and (c) understandings of the nature of scientific models, hypotheses, theories and laws.

Contingency tables were prepared for each of the items identified as being frequently missed. Chi squares for these tables were computed and the items were examined in detail.

In Tables XII, XIII, and XIV, these eight items are reproduced as they appeared on the TOUS test. The preferred response to each item is indicated as are the percentages of the members from each group who responded to each of the four choices. Chi square has been calculated in order to determine levels of significance of group differences in correctly responding to the item. The items examined are not necessarily those for which group differences are greatest.

Understandings of Characteristics of Scientists. Items 22 and 34 are two of the items most frequently missed by science teacher-candidates, social science teacher-candidates and in-service science teachers. These two items were missed by over 50 percent of the members of each of the six groups studied.

Responses to item 22 indicated that nearly 70 percent of the science teacher-candidates agreed that "certain scientific attitudes of scientists may be best observed when the scientists are doing

Table XII. TOUS Items Concerning Characteristics of Scientists with Percentages of Responses by Freshmen, Teacher-Candidates, and In-Service Science Teachers

Item 22: Scientists are often described as having certain "scientific attitudes." These may be best observed when scientists are

- A\* actually engaged in research.
- B asked to work outside their field.
- C doing most anything.
- D with their families and friends.

	n	A*	B	C	D
Freshmen - Social Science Education	19	42.1	31.6	26.3	0.0
Freshmen - Science Education	41	29.3	19.5	46.3	4.9
Elementary Teacher-Candidates	31	38.7	9.7	51.6	0.0
Social Science Teacher-Candidates	18	22.2	33.3	44.4	0.0
Science Teacher-Candidates	36	22.2	8.3	69.4	0.0
In-Service Science Teachers	42	45.2	9.5	42.9	2.4
$X^2 = 7.06$		ndf = 5	.30 > p > .20		

\*Indicates the preferred choice

p -Indicates the Level of Significance of  $X^2$ .

Table XII. Continued.

Item 34:	Scientists are honest and self-critical in their work	BECAUSE		these scientific attitudes are personal character- istics of scientists.		
	STATEMENT	REASON				
	A generally true . . . . .		generally true			
	B* generally true . . . . .		false			
	C false . . . . .		generally true			
	D false . . . . .		false			
		n	A	B*	C	D
Freshmen - Social Science Education	19	52.6	36.8	0.0	10.5	
Freshmen - Science Education	41	61.0	26.8	7.3	4.9	
Elementary Teacher-Candidates	31	38.7	58.1	3.2	0.0	
Social Science Teacher-Candidates	18	66.6	27.8	5.6	0.0	
Science Teacher-Candidates	36	50.0	41.7	2.8	5.6	
In-Service Science Teachers	42	54.8	40.5	2.4	2.4	
	$X^2 = 8.43$	ndf = 5	.20 > p > .10			

\* Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

most anything", as opposed to "when they are actually engaged in research." More than 42 percent of the in-service science teachers agreed with the science teacher-candidates.

For item 22, the calculated chi square value of 7.06 with five degrees of freedom was evaluated by consulting the table of chi square (93, p. 432). This table shows that a value as large as 7.06 would be expected in between 20 and 30 percent of random samples of the same size as the groups involved in this study, drawn from populations of which these groups were representative, if there was no group bias in answering this item.

At least half of the science teacher-candidates and in-service teachers responded to the foil on item 34 stating that "scientists are honest and self-critical in their work BECAUSE these scientific attitudes are personal characteristics of scientists." Large percentages of students in the other participating groups agreed with the science teachers. The preferred choice to this item was that the reason given should have been marked false. These traits are not necessarily personal characteristics of scientists. The chi square value of 8.43 for this item shows that the observed group differences in responding to the preferred choice for the item would be expected in between 10 and 20 percent of random samples the same size as the groups which participated in this study if there was no group bias in answering the item.

While group variations in the preferred responses to items 22 and 34 did not reveal a high level of statistical significance, the investigator considered that the educational significance of a majority of the science teacher-candidates having an inaccurate concept of the sampled characteristics of scientists should not be overlooked.

Understandings of Distinctions Between Science and Technology.

Items 12, 16, and 23, which are shown in Table XIII, are concerned with the principal aim of science, the most important contribution scientists make to society, and whether the design of a television receiver is a problem of science or of technology. Responses to these related items by the participants of the study revealed a common misconception which has been reported by Behnke (7), Belt (9), Withey (95) and many other investigators.

There was considerable agreement among the groups that the principal aim of science is "to provide the people of the world with the means of leading better lives", and that "the most important contribution scientists make to society is to make improved products for better living." This concept was more commonly held by the in-service science teachers than was the concept that "the principal aim of science is to explain natural phenomena in terms of principles and theories." Although the science teacher-candidates agreed with the preferred responses to items 12, 16 and 23 more consistently than

Table XIII. TOUS Items Concerning the Distinction Between Science and Technology with Percentage of Responses by Freshmen, Teacher-Candidates and In-Service Science Teachers

Item 12:	The principal aim of science is to				
		A	B*	C	D
	n				
Freshmen - Social Science Education	19	0.0	47.4	26.3	26.3
Freshmen - Science Education	41	2.4	22.0	26.8	48.8
Elementary Teacher-Candidates	31	0.0	29.0	12.9	58.1
Social Science Teacher-Candidates	18	0.0	38.9	38.9	22.2
Science Teacher-Candidates	36	0.0	44.4	19.4	36.1
In-Service Science Teachers	42	0.0	31.0	7.1	61.9
	$X^2 = 6.65$	ndf = 5	.30 > p > .20		

\* Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

Table XIII. Continued

Item 16: Which one of the following statements best describes the most important contribution scientists make to society?

- A\* Scientists provide knowledge about natural events.
- B Scientists make improved products for better living.
- C Scientists provide skilled services or advice to others.
- D Scientists show us what we should strive for.

	n	A*	B	C	D
Freshmen - Social Science Education	19	42.1	31.6	21.1	5.3
Freshmen - Science Education	41	17.1	73.2	7.3	0.0
Elementary Teacher-Candidates	31	45.2	38.7	12.9	3.2
Social Science Teacher-Candidates	18	50.0	33.3	11.1	5.6
Science Teacher-Candidates	36	52.8	44.4	0.0	2.8
In-Service Science Teachers	42	42.9	45.2	9.5	2.4

$$X^2 = 12.49 \quad \text{ndf} = 5 \quad .05 > p > .02$$

\* Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

Table XIII. Continued.

Item 23: The design of a television receiver is a problem of

- A science, because it calls for ingenuity and originality.
- B science, because the design must be developed by experiment.
- C\* technology, because it leads to the production of a practical device.
- D technology, because the designer must have technical ability.

	n	A	B	C*	D
Freshmen - Social Science Education	19	5.3	26.3	21.1	47.4
Freshmen - Science Education	41	4.9	17.1	41.5	36.6
Elementary Teacher-Candidates	31	0.0	41.9	38.7	19.4
Social Science Teacher-Candidates	18	0.0	33.3	38.9	27.8
Science Teacher-Candidates	36	2.8	22.2	52.8	22.2
In-Service Science Teachers	42	7.1	21.4	47.6	23.8
$X^2 = 5.82$		ndf = 5	.50 > p > .30		

\* Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

did any other group, approximately half of these students missed each of the three items.

The general agreement between the responses of freshmen in science education and the in-service science teachers indicated that science teachers may transfer their concepts (and misconceptions) of science to the students they teach. Additional, but inconclusive, support was given to this hypothesis by the fact that the freshmen in social science education, a group of students who had studied less science in high school, selected the preferred choice to the above mentioned items more frequently than did the freshmen in science education.

Understandings of the Nature of Scientific Hypotheses, Theories and Laws. An item-to-item comparison of the responses of the participating groups to Items 30, 43, and 46 revealed substantial differences in understandings relative to the nature of scientific hypotheses, theories, and laws. Several misconceptions of the nature of science were revealed.

The science teacher-candidates and in-service science teachers were both in higher agreement with the preferred responses on the items in this area than was true for the previously considered categories concerning characteristics of scientists and the basic goals of science. The small differences which did exist between these two

groups were in favor of the in-service science teachers.

On the question of the best description of a scientific law, more of the science education freshmen agreed that a scientific law "is enforced by nature and cannot be violated", than accepted the statement that "a scientific law is a generalized statement of relationships among natural phenomena." This group was more successful in identifying a statement in Item 46 as describing a scientific law, yet over 46 percent identified it incorrectly as describing a theory. Fewer than half of these freshmen who were planning to become science teachers responded to Item 30 in such a way as to reveal an understanding that "the atom as a miniature solar system", is not what scientists could see with very powerful instruments. This analysis revealed that these science-prone students left high school with some definite misconceptions of the nature of science.

The science teacher-candidates revealed understandings of the nature of scientific hypotheses, theories and laws which were in higher agreement with the preferred responses than did both groups of freshmen or the groups of non-science teacher-candidates. Responses of the science teacher-candidates are shown in Table XIV to be fairly consistent with those of the in-service science teachers.

### Summary

Analyses of three groups of TOUS items which were commonly

Table XIV. TOUS Items Concerning Understandings of the Nature of Scientific Models, Hypotheses, Theories and Laws by Freshmen, Teacher-Candidates and In-Service Science Teachers

Item 30: An example of a scientific model is: "The atom is like a miniature solar system composed of electrons in orbits, and, in the center, a nucleus containing protons and neutrons." Which one of the following statements about scientific models is NOT correct?

- A They are man-made constructs and may not represent reality.
- B They consist of a relatively small number of assumptions.
- C\* They represent what scientists could see with very powerful instruments.
- D They are tentative and may be modified or discarded.

	n	A	B	C*	D	No Response
Freshmen - Social Science Education	19	21.1	47.4	26.3	5.3	0.0
Freshmen - Science Education	41	24.4	14.6	46.3	9.8	4.9
Elementary Teacher-Candidates	31	16.1	45.2	29.0	9.7	0.0
Social Science Teacher-Candidates	18	33.3	33.3	27.8	5.6	0.0
Science Teacher-Candidates	36	13.9	25.0	52.8	8.3	0.0
In-Service Science Teachers	42	4.8	16.7	78.6	0.0	0.0

$$X^2 = 24.56 \quad \text{ndf} = 5$$

$$p > .01$$

\*Indicates the preferred choice.

p = Indicates the Level of Significance of  $X^2$ .

Table XIV. Continued

Item 43: Which of the following is the best description of a scientific law?

- A It is an exact report of the observations of scientists.
- B\* It is a generalized statement of relationships among natural phenomena.
- C It is a theoretical explanation of a natural phenomenon.
- D It is enforced by nature and cannot be violated.

	n	A	B*	C	D	No Response
Freshmen - Social Science Education	19	0.0	26.3	68.4	5.3	0.0
Freshmen - Science Education	41	22.0	17.1	39.0	22.0	0.0
Elementary Teacher-Candidates	31	6.5	54.8	29.0	9.7	0.0
Social Science Teacher-Candidates	18	5.6	55.6	27.8	11.1	0.0
Science Teacher-Candidates	36	2.8	58.3	30.6	5.6	2.8
In-Service Science Teachers	42	4.8	64.3	21.4	9.5	0.0

$$X^2 = 34.90 \quad \text{ndf} = 5 \quad p > .01$$

\*Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

Table XIV. Continued

Item 46: Gay-Lussac carried out many experiments with gases and observed that when heat is applied to gases their volumes always increase, providing the pressure remains the same. Gay-Lussac decided that "at constant pressure, the volume of a gas varied directly with the temperature." This is an example of

- A formulation of a scientific theory.
- B\* testing of a scientific hypothesis.
- C formulation of a scientific law.
- D reasoning from the abstract to the concrete.

	n	A	B	C*	D
Freshmen - Social Science Education	19	42.1	10.5	42.1	5.3
Freshmen - Science Education	41	46.3	4.9	41.5	7.3
Elementary Teacher-Candidates	31	41.9	22.6	32.3	3.2
Social Science Teacher-Candidates	18	50.0	16.7	33.3	0.0
Science Teacher Candidates	36	41.7	0.0	55.5	2.8
In-Service Science Teachers	42	28.6	7.1	61.9	4.8

$X^2 = 10.76$       ndf = 5      .20 > p > .10

\* Indicates the preferred choice.

p - Indicates the Level of Significance of  $X^2$ .

missed by students in all six groups which participated in the study, revealed that some misconceptions of science and scientists existed among the in-service science teachers and science teacher-candidates. These misconceptions were even more pronounced among students who had just completed high school or who were teacher-candidates in social science or elementary education.

Most striking of these misconceptions were: (a) that scientists tend to be honest and self-critical in their work BECAUSE these scientific attitudes are personal characteristics of scientists, and (b) that the most important contributions that scientists make to society are improved products for better living. Although students in all of the groups experienced difficulty in distinguishing among the nature of scientific models, hypotheses, theories and laws, differences between the groups in selecting the preferred response was statistically significant at the one percent level for two of the three items. Science oriented groups scored higher on these items than did the non-science oriented groups.

#### Tests of the Hypotheses

In the tests of the hypotheses, the statistical model employed was the single classification analysis of covariance outlined by Wert (93, p. 344). Group means were used as the unit of analysis, since it was group differences rather than individual student differences

that were tested. The criterion measure in half of the tests of the hypotheses was the Cornell Critical Thinking Test group mean. The Test on Understanding Science group mean was the criterion measure in the other half of the tests.

The group means of: (a) the combined verbal and mathematical subtest scores on the Scholastic Aptitude Test, and (b) accumulative college grade point averages were applied as covariance controls to the CCTT and TOUS group means.

F ratios were computed using the difference between the total and within mean squares as the numerator, and the adjusted within mean squares as the denominator in each instance. F ratios were evaluated by consulting a Table of the five and one percent values of F (93, p. 419).

When the F ratio was large enough to indicate statistical significance beyond the five percent level of confidence, the investigator concluded that when the criterion means of the two groups were adjusted for individual differences in scholastic aptitude and academic achievement, the differences were so large that they were not caused by a sampling accident. Presumably the difference can be attributed to formal and informal learning experiences of the subjects. This study was concerned with differences in critical thinking ability and understandings of science which may have resulted from the study of different curricula specifically designed for the education of teachers.

In this section, tests of the null hypotheses which were stated in Chapter I are presented and discussed. For convenience in discussing the findings, the null hypotheses are grouped as follows: (a) hypotheses concerning group differences in critical thinking ability, (b) hypotheses concerning group differences in understandings of science, and (c) hypotheses relating to science teacher-candidate subgroup differences in critical thinking ability, and understanding of science.

#### Hypotheses Concerning Group Differences in Critical Thinking Ability

Null hypotheses one through five asserted that there is no difference in critical thinking ability between science teacher-candidates and the critical thinking abilities of: (a) freshmen in social science education, (b) freshmen in science education, (c) elementary teacher-candidates, (d) social science teacher-candidates, and (e) in-service science teachers. Table XV is the analysis of covariance table for the Cornell Critical Thinking Test total scores.

The table shows that hypothesis 3, which stated that there is no difference in critical thinking ability between science teacher-candidates and the critical thinking ability of teacher-candidates in social science, was accepted. Hypotheses 1, and 5 asserting that there is no difference in critical thinking ability between science

Table XV. Relationship of Critical Thinking Ability of Science Teacher-Candidates to That of Freshmen, Elementary and Social Science Teacher-Candidates, and In-Service Science Teachers

Group	n	CCTT Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for SAT(V+M) and GPA		ndf	F Ratio	Level of Signifi- cance
					Total	Within			
Freshmen - Social Science Education	19	54.32	983.89	2.34					
Science Teacher- Candidates	36	59.47	1088.67	2.88	2135.945	1462.445	1,51	23.487	<.01
Freshmen - Science Education	41	56.46	1076.02	2.45					
Science Teacher- Candidates	36	59.47	1088.67	2.88	2022.320	1886.082	1,73	5.273	<.05
Elementary Teacher- Candidates	31	52.97	912.48	2.59					
Science Teacher- Candidates	36	59.47	1088.67	2.88	2389.239	2230.034	1,63	4.498	<.05
Social Science Teacher-Candidates	18	57.17	993.44	2.66					
Science Teacher- Candidates	36	59.47	1088.67	2.88	1504.365	1503.822	1,50	.018	
In-Service Science Teachers	42	57.93	1226.12	3.05					
Science Teacher- Candidates	36	59.47	1088.67	2.88	2756.023	2408.936	1,74	10.662	<.01

teacher-candidates and the critical thinking ability of either freshmen in social science or in-service science teachers, were rejected at the one percent level of confidence. Hypotheses 2 and 4 which stated that there is no difference in critical thinking ability between science teacher candidates and either freshmen in science education or elementary teacher-candidates, were rejected at the five percent level of confidence. The observed differences in group means on the Cornell Critical Thinking Test, when adjusted for individual differences in scholastic aptitude and academic achievement, were so large that they would have been expected in less than one or five percent of samples of the same size drawn from similar populations if there had been no group bias in CCTT scores.

Summary. The social science teacher-candidates who participated in this study did not differ significantly in critical thinking abilities, as measured by the criterion instrument, from the science teacher-candidates. The critical thinking abilities of the science teacher-candidates, as measured by the criterion instrument, were shown to be significantly greater than those of freshmen in social science education (one percent level), science education freshmen (five percent level), elementary teacher-candidates (five percent level), and in-service science teachers (one percent level).

### Hypotheses Concerning Group Differences in Understanding of Science

Null hypotheses 6 through 10 stated that there is no difference in understanding of science between science teacher-candidates and that of: (a) freshmen in social science education, (b) freshmen in science education, (c) elementary teacher-candidates, (d) social science teacher-candidates, and (e) in-service science teachers.

Table XVI is the analysis of covariance table for the Test on Understanding Science total scores.

The table shows that null hypothesis 8 which stated that there is no difference in understanding of science between science teacher-candidates and teacher-candidates in social science was accepted. Null hypotheses 6, 7, and 9 stating that there is no difference in understanding of science between science teacher-candidates and freshmen in social science, freshmen in science education, and elementary teacher-candidates were rejected at the one percent level of confidence. Hypothesis 10 which asserted that there is no difference in understanding of science between science teacher-candidates and in-service science teachers was rejected at the five percent level.

Summary. Social science teacher-candidates who participated in this study did not differ significantly in understanding of science, as measured on the criterion instrument, from science teacher-candidates. The understanding of science of science teacher-

Table XVI. Relationship of Understanding of Science of Science Teacher-Candidates to That of Science Education and Social Science Education Freshmen, Elementary and Social Science Teacher-Candidates, and In-Service Science Teachers

Group	n	TOUS Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for		ndf	F Ratio	Level of Significance
					SAT(V+M)and GPA Total	Within			
Freshmen - Social Science Education	19	36.00	983.89	2.34					
Science Teacher-Candidates	36	46.31	1088.67	2.88	1567.850	822.292	1,51	46.241	<.01
Freshmen - Science Education	41	37.02	1076.02	2.45					
Science Teacher-Candidates	36	46.31	1088.67	2.88	2828.442	1289.827	1,73	87.081	<.01
Elementary Teacher-Candidates	31	39.84	912.48	2.59					
Science Teacher-Candidates	36	46.31	1088.67	2.88	1151.072	987.163	1,63	10.461	<.01
Social Science Teacher-Candidates	18	42.56	993.44	2.66					
Science Teacher-Candidates	36	46.31	1088.67	2.88	1065.364	1029.574	1,50	1.738	
In-Service Science Teachers	42	47.21	1226.12	3.05					
Science Teacher-Candidates	36	46.31	1088.67	2.88	1121.650	1073.628	1,74	3.310	<.05

candidates, as measured on the criterion instrument, was significantly greater than that of freshmen in social science education (one percent level), freshmen in science education (one percent level), elementary teacher-candidates (one percent level), and in-service science teachers (five percent level). It should be noted that although the mean TOUS score for the in-service science teachers was 0.90 points higher than that of the science teacher-candidates, when covariance controls for the 137 point superiority in SAT (V + M) mean and 0.17 point superiority in GPA of the in-service science teachers were applied, the calculated F ratio was large enough to make the difference in TOUS group means statistically significant in favor of the science teacher-candidates. The educational significance of this difference is, however, open to question.

Hypotheses Concerning Science Teacher-Candidate Subgroup Differences in Critical Thinking Ability and Understanding of Science

To explore further the possible effects of science curricula on the development of critical thinking abilities and understanding of science, several subgroups of science teacher-candidates were identified for investigation. Variables selected as bases for subgroup identification were: (a) sex, (b) the total number of grade points earned in biological and physical science courses, (c) the biological science-physical science ratio of quarter hours completed in

science, and (d) the number of quarter hours completed in mathematics.

Differences between High and Low Subgroups Based on the Total Number of Science Grade Points Earned. Table XVII is the analysis of covariance table for CCTT and TOUS scores of high and low subgroups identified on the basis of total number of grade points earned in college courses in biological and physical science. The total number of grade points earned in these courses was selected as a criterion for subgroup identification because it took into consideration both quantity of science studied and achievement in science. The table shows that students in the high subgroup, as a group, had earned nearly twice as many grade points in biological and physical science courses as had students in the low subgroup.

The small observed differences in subgroup means on both of the criterion tests, when controlled for differences in scholastic aptitude and academic achievement, were not statistically significant. This finding resulted in the acceptance of both null hypotheses 11 and 14. These hypotheses asserted that there is no difference in critical thinking ability or in understanding of science between science teacher-candidates in high and low subgroups, based on the total number of science grade points earned.

Summary. The total number of grade points earned by science

Table XVII. Relationship of the Total Number of Grade Points Earned in Biological and Physical Sciences to the Critical Thinking Ability and the Understanding of Science of Science Teacher-Candidates

Criterion	Subgroup:		Criterion Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for SAT(V+M) and GPA		F Ratio (ndf:1, 32)	Level of Significance
	Total Science Grade Point	n				Total	Within		
Cornell Critical Thinking Test	Low:	<u>93.8*</u>	18	58.7	1100	2.73			
	High:	<u>182.2</u>	18	57.7	1077	3.03	1080.800	1072.184	.257
-----									
Test on Under- standing Science	Low:	<u>93.8</u>	18	45.7	1100	2.73			
	High:	<u>182.2</u>	18	46.9	1077	3.03	502.851	477.634	1.689

\* Indicates the mean number of grade points earned in biological and physical science by the subgroup.

teacher-candidates was not significantly related to either critical thinking abilities or understanding of science as measured by the criterion instruments.

Differences Between High and Low Subgroups Based on the Biological Science-Physical Science Ratio of Science Credits Completed. Null hypotheses 12 and 15 stated that there is no difference in critical thinking ability or understanding of science between science teacher-candidates in high and low subgroups based on the biological science-physical science ratio of science credits completed. Both of these hypotheses were accepted on the basis of data shown in Table XVIII.

This table is the analysis of covariance table for CCTT and TOUS total scores of science teacher-candidate subgroups. Although students in the high and low subgroups had biological science-physical science credit ratios of 1.91:1 and 0.30:1 respectively, differences between group means on the criterion tests were not statistically significant.

Summary. The biological science-physical science ratio of science credits completed was not significantly related to either critical thinking ability or understanding of science as measured by the criterion instruments. The group with a physical science emphasis in coursework scored higher on both of the criterion tests and on

Table XVIII. Relationship of Biological Science-Physical Science Credit Ratio to the Critical Thinking Ability and Understanding of Science of Science Teacher-Candidates

Criterion	Subgroup:		Criterion Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for		F Ratio (ndf:1, 32)	Level of Significance
	B. S. - P. S. Credit Ratio	n				SAT(V+M) and GPA Total	Within		
Cornell Critical Thinking Test	Low: $\overline{.30:1}^*$	18	59.39	1123	2.84				
	High: $\overline{1.91:1}$	18	57.00	1055	2.86	1080.784	1060.770	.604	
-----									
Test on Under- standing Science	Low: $\overline{.30:1}$	18	47.89	1123	2.84				
	High: $\overline{1.91:1}$	18	44.75	1055	2.86	502.851	475.396	1.84	

\* Indicates the mean ratio of biological science to physical science credits completed by the subgroup.

the Scholastic Aptitude Tests than did the group with a biological science emphasis. The latter group had earned a slightly higher accumulative GPA, however.

Differences Between High and Low Subgroups Based on the Number of Quarter Hours Completed in Mathematics. The data shown in Table XIX resulted in the investigator accepting both null hypotheses 13 and 16 which asserted that there is no difference in critical thinking ability or understanding of science between science teacher-candidates in high and low subgroups based on the total number of mathematics credits completed. Although the high and low subgroups differed by a factor of 3.2 in terms of the mean number of quarter hours of college mathematics completed, differences between the group mean scores on the criterion tests were not statistically significant.

Summary. The number of quarter hours completed in mathematics was not significantly related to either the critical thinking ability or the understanding of science of the science teacher-candidates. Mean scores for the high subgroup were 1.5 points higher on each criterion test and nearly 100 points higher on the SAT (V + M) tests than were scores for the low subgroup.

Table XIX. Relationship of the Number of Quarter Hours Completed in Mathematics to the Critical Thinking Ability and Understanding of Science of Science Teacher-Candidates

Criterion	Subgroup Mathematics		Criterion Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for SAT(V+M) and GPA		F Ratio (ndf: 1,32)	Level of Significance
	Credit	n				Total	Within		
Cornell Critical Thinking Test	Low: $\overline{13.3}^*$	18	57.4	1039	2.87	1080.800	1065.573	.457	
	High: $\overline{41.1}$	18	59.0	1137	2.89				
- - - - -									
Test on Understanding Science	Low: $\overline{13.3}$	18	45.6	1039	2.87	502.851	490.312	.818	
	High: $\overline{41.1}$	18	47.1	1137	2.89				

\* Indicates mean number of quarter hours of mathematics completed by the subgroup.

Differences Between Male and Female Science Teacher-  
Candidates in Critical Thinking Ability and Understanding of Science.

Although sex is not a curriculum factor, the investigator hypothesized that commonly stated claims that "boys are better in science than girls", might be profitably examined with respect to the critical thinking abilities and understanding of science of male science teacher-candidates as compared to female science teacher-candidates. Table XX is the analysis of covariance table for CCTT and TOUS total scores of these two groups.

The table reveals that null hypothesis 11 which stated that there is no difference between male and female science teacher-candidates with respect to critical thinking ability, was accepted. Null hypothesis 12 which asserted that there is no difference between male and female science teacher-candidates with respect to understanding of science, was rejected at the five percent level of confidence. Although the difference between the group mean TOUS score for the males and the females was only 0.7 point, the 86 point greater SAT (V + M) mean and 0.30 point greater GPA for the females, when applied as covariance controls to the TOUS means, resulted in this difference becoming statistically significant in favor of the males.

Summary. Although the female science teacher-candidates

Table XX. Relationship of Sex of Science Teacher-Candidates to Critical Thinking Ability and Understanding of Science

Criterion	Subgroup: Sex	n	Criterion Mean	SAT(V+M) Mean	Mean GPA	SS Adjusted for SAT(V+M) and GPA		F Ratio (ndf:1, 32)	Level of Signifi- cance
						Total	Within		
Cornell Critical Thinking Test	Male	17	58.94	1043.06	2.72				
	Female	19	59.95	1129.47	3.02	1080.800	1073.315	.223	
-----									
Test on Under- standing Science	Male	17	46.71	1043.06	2.72				
	Female	19	45.95	1129.47	3.02	502.851	433.194	5.146	<.05

participating in this study had higher mean Scholastic Aptitude Test scores and higher mean grade point averages than did the males, there was no statistically significant difference between the two groups in critical thinking ability as measured by mean total scores on the Cornell Critical Thinking Test. The male science teacher-candidates, as a group, had a significantly (at the five percent level) higher score on the Test on Understanding Science than did the females.

### Summary

Single classification analyses of covariance using group CCTT and TOUS means were employed to statistically test the null hypotheses. SAT (V + M) group means and group mean GPA's were applied as covariance controls to the CCTT and TOUS group means. F ratios were computed and tested to determine whether differences in group means on the criterion tests were significant.

Differences in both CCTT and TOUS group means between the social science teacher-candidates and science teacher-candidates were not statistically significant. Differences between group means of the science teacher-candidates on both the Cornell Critical Thinking Test and Test on Understanding Science and the group means of: (a) freshmen in social science education, (b) science education freshmen, (c) elementary teacher-candidates, and (d) in-service

science teachers were found to be statistically significant at the five percent level. In each instance, the high mean was in favor of the science teacher-candidates.

The same statistical test was used to test hypotheses relative to the critical thinking abilities and understandings of science of subgroups of science teacher-candidates. Hypotheses that there is no difference in critical thinking ability or understanding of science between high and low subgroups of science teacher-candidates based on: (a) the total number of science grade points earned, (b) the biological science-physical science ratio of science credits completed, and (c) the number of mathematics credits completed were all accepted. While the hypothesis that there is no difference in critical thinking ability between male and female science teacher-candidates was accepted, the hypothesis that there is no difference in understanding of science between these two groups was rejected at the five percent level of confidence.

## CHAPTER V

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study was designed to determine the extent to which students who are completing planned curricula in science education: (a) are proficient in aspects of critical thinking, and (b) possess understandings of science consistent with those of the practicing scientist. The effect of science curricula upon the development of these abilities and understandings was examined by comparing group mean test scores of science teacher-candidates to those of five groups of teachers or students in teacher education which differed substantially in college science preparation. Finally, subgroups of science teacher-candidates were compared in order to assess further the effect of science curricula upon the development of critical thinking abilities and understandings of science.

Participants in the study were: (a) 19 freshmen in social science education, (b) 41 freshmen in science education, (c) 31 elementary teacher-candidates, (d) 18 social science teacher-candidates, (e) 36 science teacher-candidates, and (f) 42 in-service science teachers represented by Academic Year Institute Participants. All participants in the study were students at Oregon State

University during the 1964-65 academic year when the study was conducted.

Criterion tests were the Cornell Critical Thinking Test, Form X and the Test on Understanding Science, Form W. The study being of a post-test only design, the criterion instruments were administered to the freshmen and in-service teachers at the beginning of Fall Term. Teacher-candidates completed these tests during the term that they were enrolled in their respective special teaching methods courses.

Combined verbal and mathematical subtest means on the Scholastic Aptitude Test served as controls of scholastic aptitude while accumulative college grade point averages were used to control for group differences in academic achievement.

Analyses of the data revealed differences of group CCTT and TOUS means amounting to over six and ten points respectively. The science teacher-candidates obtained the highest Cornell Critical Thinking Test group mean and were second to the in-service science teachers (by 0.90 points) on TOUS group means. Both of the criterion tests were significantly correlated to Scholastic Aptitude Test scores for a majority of the groups. While TOUS scores were significantly correlated to both accumulative and science grade point averages in nine out of ten correlations, CCTT scores were not observed to be significantly correlated to grade point averages for any

of the groups.

CCTT scores were observed to be negatively correlated to both the number of quarter hours completed in biological and physical science and to the total number of science grade points earned by members of each participating group. TOUS scores were observed to be negatively correlated to both the total number of quarter hours completed in science, and to the total number of science grade points earned by two of the groups. For two other groups, these correlations were positive but non-significant.

For the science teacher-candidates, both CCTT and TOUS scores showed significant (at the five percent level) negative correlations to the total number of science grade points earned.

An analysis of TOUS items which were frequently missed by students in all of the participating groups revealed two areas in which misconceptions of the nature of science and scientists prevailed. These misconceptions may be summarized as follows: (a) scientists are honest and self-critical in their work BECAUSE these are personal characteristics of scientists, and scientific attitudes of scientists may be BEST observed when scientists are doing most anything; and (b) the principal aim of science and scientists is to provide the people of the world with improved products for better living. These misconceptions were as commonly held by science teacher-candidates and in-service science teachers as by any of the other

groups. Although students in all of the groups experienced difficulty in distinguishing among scientific models, hypotheses, theories and laws, the in-service science teachers and the science teacher-candidates evidenced fewer misunderstandings in this area than did students in the other groups.

Single classification analyses of covariance using TOUS and CCTT group means were employed to statistically test the null hypotheses. SAT (V + M) group means and group mean GPA's were applied as covariance controls to the CCTT and TOUS group means. F ratios were computed and evaluated to determine whether differences in group means on the criterion instruments were significant.

These tests resulted in the acceptance of the null hypotheses that there is no difference in either critical thinking ability or in understanding of science between science teacher-candidates and social science teacher-candidates. Similar null hypotheses concerning differences in both critical thinking ability and understanding of science between science teacher-candidates and: (a) freshmen in social science, (b) science education freshmen, (c) elementary teacher-candidates, and (d) in-service science teachers were all rejected at either the one or the five percent level of confidence. For the hypotheses which were rejected, the differences between group means on the Cornell Critical Thinking Test or on the Test on Understanding Science, all of which were in favor of the science teacher-candidates,

were so great that they would be expected in fewer than one or five percent of random samples of the same size selected from populations of which each of these groups was representative, if there had been no group bias in CCTT and TOUS total mean scores.

In order to assess further effects of science curricula on the development of critical thinking ability and understanding of science, the same statistical test was used to test hypotheses relative to the critical thinking abilities and understandings of science of subgroups of science teacher-candidates. Subgroups were selected on the basis of: (a) the total number of science grade points earned, (b) the biological science-physical science ratio of science credits completed, and (c) the total number of quarter hours of mathematics completed. The hypothesis that there is no difference in critical thinking ability between male and female science teacher-candidates was accepted; the hypothesis that there is no difference in understanding of science between these two groups was rejected at the five percent level of confidence.

### Conclusions

The following conclusions were drawn from the data presented in this investigation:

1. Critical thinking abilities of science teacher-candidates were significantly greater (at the five percent level) than

those of freshmen in social science education, freshmen in science education, elementary teacher-candidates, and in-service science teachers.

2. Science teacher-candidates did not differ significantly from social science teacher-candidates in critical thinking ability.
3. Critical thinking ability, as measured by the criterion instrument, was not a major learning outcome of the study of college science. This conclusion was based on:
  - a) Negative, but non-significant correlations between Cornell Critical Thinking Test scores and both the number of college science credits completed and the total number of science grade points earned by members of all but one of the participating groups. The one exception was the significant negative correlation between CCTT scores and the total number of science grade points earned by the science teacher-candidates.
  - b) The lack of a significant difference in critical thinking ability between science teacher-candidates and social science teacher-candidates, the latter group having completed half as many credits in science as had the former.
  - c) Failure to find a significant difference in critical thinking ability between high and low subgroups of

science teacher-candidates selected on each of the following bases:

- 1) Total number of science grade points earned.
  - 2) The biological science-physical science ratio of science credits completed.
  - 3) The number of quarter hours of college mathematics completed.
4. The critical thinking ability of male science teacher-candidates was not significantly different from that of the female science teacher-candidates.
  5. Some factor other than the amount and type of college science studied, scholastic aptitude, and academic achievement was responsible for the significant differences in critical thinking ability between the science teacher-candidates and freshmen in social science education, freshmen in science education, elementary teacher-candidates, and in-service science teachers.
  6. Understanding of science of science teacher-candidates was significantly greater (at the five percent level) than that of freshmen in social science education, freshmen in science education, elementary teacher-candidates and in-service science teachers.
  7. Science teacher-candidates did not differ significantly from

social science teacher-candidates in understanding of science.

8. Science teacher-candidates evidenced an understanding of science superior to that of groups of over 2500 high school students to whom the TOUS test had been administered (60, p. 36). These high school students were similar to groups of students that the science teacher-candidates would be expected to teach.
9. Science teacher-candidates and in-service science teachers evidenced several misconceptions of the nature of science and scientists.
10. Although all groups revealed misunderstandings of the nature of scientific models, hypotheses, theories, and laws, these misunderstandings were significantly more numerous for groups whose members had studied relatively little college science than for those groups whose members had earned relatively large numbers of college science credits.
11. Understanding of science, as measured on the criterion instrument, was not a major learning outcome of the study of college science. Evidence for this conclusion was:
  - a) With only one exception, TOUS scores were not

significantly correlated to either the total number of college science credits completed or to the total number of science grade points earned by members of any of the participating groups. The one exception was a significant negative correlation between TOUS scores and the total number of science grade points earned by the science teacher-candidates.

- b) Failure to find a significant difference in understanding of science between science teacher-candidates and social science teacher-candidates, the former group having completed twice as many credits in science as had the latter.
- c) The lack of significant difference in understanding of science between high and low subgroups of science teacher-candidates selected on each of the following bases:
  - 1) Total number of science grade points earned.
  - 2) The biological science-physical science ratio of science credits completed.
  - 3) The number of quarter hours of college mathematics completed.

12. The understanding of science of male science teacher-candidates was statistically superior (at the five percent

level) to that of female science teacher-candidates.

13. Some factor other than the amount and type of college science studied, scholastic aptitude, and academic achievement was responsible for the significant difference in understanding of science which was observed between science teacher-candidates and freshmen in social science, freshmen in science education, elementary teacher-candidates, and in-service science teachers.

#### Recommendations

On the basis of the data presented in this study, the investigator recommends that:

1. Consideration should be given to completing the following investigations:
  - a) Replication studies to determine if:
    - 1) Other groups of science teacher-candidates consistently score higher on the criterion instruments than other groups of freshmen in social science, freshmen in science education, elementary teacher-candidates, and in-service science teachers.
    - 2) Non-significant and negative correlations are consistently observed between scores on the criterion instruments and both the number of science credits

completed and the total number of science grade points earned.

- 3) Non-significant differences consistently exist between other high and low subgroups of science teacher-candidates selected on the basis of total number of science credits completed, biological science-physical science ratio of science course work completed, or the total number of quarter hours of mathematics completed.
  - b) A study to determine the critical thinking abilities and understandings of science of groups of science students who are not planning to teach.
  - c) A three- or four-year longitudinal study to determine the gains in critical thinking ability and understandings of science which may result from college curricula studied by the freshmen who participated in this study.
2. Instructors of college science courses should:
- a) Determine whether the development of critical thinking abilities and understandings of science should be learning outcomes of students studying their courses.
  - b) Precisely define the aspects of critical thinking and the understandings of science which students should develop as a result of having studied a given course.

- c) Provide learning activities specifically designed to develop critical thinking abilities and understandings of science by students in science courses in which these learning outcomes are considered to be important.
  - d) Place appropriate emphasis on evaluation procedures and test items which will require the student to demonstrate proficiency in aspects of critical thinking and to reveal understandings of the nature of science consistent with those of the practicing scientists in order to respond correctly to the test item or to receive a high evaluation.
  - e) Revise or replace learning activities which have been specifically designed to develop aspects of critical thinking or understandings of science in instances where the evaluation instruments reveal that the desired learning outcomes are not being attained.
3. Individuals directly responsible for the pre- and in-service education of science teachers should:
- a) Determine which combinations of existing science courses and instructors contribute most to the development of critical thinking abilities and understandings of science.
  - b) Encourage science instructors to develop learning

activities which show promise of developing aspects of critical thinking and understandings of science.

c) Revise teacher education curricula to include science and non-science courses which give evidence of developing students' critical thinking abilities and understandings of science.

e) Provide learning activities specifically designed to develop the critical thinking abilities and understandings of science of the teacher-candidates and the in-service teachers which are students in their classes and seminars.

4. Science teacher-candidates and in-service science teachers should be encouraged to teach in such a way as to develop in their students aspects of critical thinking and understandings of science which are measured by the Cornell Critical Thinking Test and the Test on Understanding Science.

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